AERONCA, INC.

GERMANTOWN ROAD - MIDDLETOWN, OHIO

VOLUME II - MANUFACTURING AND TESTING

FINAL REPORT

DEVELOPMENT OF HIGH STRENGTH, BRAZED ALUMINUM, HONEYCOMB SANDWICH COMPOSITES ADAPTABLE FOR BOTH ELEVATED & CRYOGENIC TEMPERATURE APPLICATIONS

FOR

GEORGE C. MARSHALL SPACE FLIGHT CENTER

NASA, HUNTSVILLE, ALABAMA

CONTRACT NO. NAS 8-5445

PERIOD OF PERFORMANCE JULY, 1963 THROUGH SEPTEMBER, 1966

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NOTICES

This report was prepared by the Middletown Division of Aeronca, Inc. under NAS8-5445, "Development of High Strength, Brazed Aluminum, Honeycomb Sandwich Composites Adaptable for Both Elevated and Cryogenic Temperature Applications", for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the technical direction of the Propulsion and Vehicle Engineering Division, Engineering Materials Branch of the George C. Marshall Space Flight Center with F. P. La Iacona acting as Project Manager.

ABSTRACT

This report is the second of two volumes on the fluxless brazing of high strength aluminum alloys, contract NAS 8-5445, covering the period July 1964 through September 1966. In addition to the present two volumes, an annotated bibliography on aluminum brazing was published separately.

The results obtained in this program have demonstrated the inert atmosphere fluxless brazing of heat treatable aluminum honeycomb sandwich structures of X7005, X7106 and 7039. Such honeycomb sandwich panels exhibited a high degree of retention of the base metal properties through the temperature range of -423°F to 600°F. In particular, the flatwise tension and peel strengths were superior to adhesive bonded configurations.

It was concluded that optimum brazing alloy wetting and flow required the brazing alloy clad onto the substrate metal. The use of separately placed brazing alloy foil produced less than optimum results; but acceptable brazements were produced by that method.

The experimental results from quenching and heat treating studies showed that aluminum honeycomb sandwich panels can be quenched into liquid nitrogen with minimum distortion. Large flat and cylindrical section sandwich brazements were fabricated by that method. Consequently, high strength alloys with rapid quench rate requirements may be utilized for both core and facing materials.

Brazing alloys of the systems Al-Ge-Si-Zn and Al-Ge-Si-Ag were developed that are promising for brazing X7106 at a temperature of approximately 1000°F. Preliminary results showed these brazing alloys to have markedly less diffusion into X7106, with consequent higher retention of base metal properties, compared with the commercially available 716 or 719 brazing

alloys. However, the majority of the brazing tests reported were brazed with alloys 716 and 719 at temperatures ranging from 1050° to 1090°F. Alloy 719 was the optimum choice and methods were developed to reduce it to foil. Other tests demonstrated that alloy 719 could be used in wire form by flame spraying it onto sandwich facing sheets.

As in other reactive brazing systems, certain limits exist for the minimum material thickness that can be joined. Consequently, the best applications for brazed aluminum honeycomb sandwich would be for heavily loaded applications requiring thick facings with high core densities.

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1. INTRODUCTION

During the first year of this program methods were developed for the fluxless brazing and air quenching of aluminum alloy honeycomb core sandwiches using readily available brazing alloys. After brazeability screening tests had been conducted, brazing alloys No. 716 and No. 719 were selected for the sandwich panel brazing and testing program. Sandwich facing materials were X7005, X7106 and 7039.

Facing tensile properties (room temperature) of the brazed and heat treated sandwich panels were the following:

Sandwich Facing Material, 0.062" Thick	Brazing Alloy	Tensile Strength psi	Yield Strength psi	Elongation Per Cent
X7005	No. 719	46,000	39,000	5
X7106	No. 716	39,000	33,000	6
7039	No. 719	40,000	34,000	4

The tensile and yield strengths of brazed X7005 exceeded the published tensile minimum values for bare X7005. On the other hand, X7106 and 7039 required faster quenching rates than were achieved; consequently, their strengths after brazing were below published minimum values for bare materials. Subsequently, brazed 7039 sandwiches were quenched by forced air and brazed X7106 sandwiches were quenched into liquid nitrogen. Their respective facing tensile properties (room temperature) were the following:

Sandwich Facing Material and Quenching Method	Brazing Alloy	Tensile Strength psi	Yield Strength psi	Elongation Per Cent
7039 Forced Air Quench	No. 719	45,000	43,000	2
X7106 Liquid Nitrogen Quench	No. 716	58,000	48,000	13

These data indicated that brazed 7039 and X7106 could be expected to meet published tensile minimum values for bare material, provided they were properly heat treated. However, metallographic examination showed that 7039 and X7106 were susceptible to brazing alloy penetration and diffusion effects, as evidenced by grain growth, to depths ranging from 0.010" to 0.060". The brazing alloy diffusion had little effect on tensile yield strengths, but significantly reduced tensile ultimate strengths and tensile elongations. The magnitude of the diffusion effects was dependent on the time and temperature during brazing. For example, the percent elongations listed above (2% for brazed 7039 and 13% for brazed X7106) could not be accepted without the knowledge that 7039 was slightly "over-brazed" (large brazing alloy diffusion effect) and that X7106 was slightly "under-brazed" (small brazing alloy diffusion effect).

In contrast, there was neglible diffusion of the No. 719 brazing alloy into X7005. Even 0.005" thick X7005 foil could be brazed with the No. 719 alloy. However, the tensile data show that the elongation of 0.062" thick X7005 was reduced from a nominal 12% to 5% by a coating of the No. 719 brazing alloy.

Brazed X7005 and X7106 increased in strength and ductility as the testing temperature was decreased to -423°F. Moreover, the sandwich mechanical tests showed that both the No. 716 and No. 719 brazed joints evidenced ductile failures at -423 F.

Brazing alloy placement, during the first year, was dictated by the form of the available materials. Alloys No. 719 and No. 716 were only available as wire (Experimental quantities of No. 716 sheet also were available). Fluxless brazing tests of these alloys in powder form were unsuccessful. Metallized brazing alloy coatings were evaluated by oxy-acetylene flame spraying 1/8" diameter brazing alloy wires to deposit brazing alloy coatings onto sandwich facing sheets, followed by brazing tests. Although flame spraying has well known limitations, it was found that successful core-to-face joints could be produced when the brazing alloy was placed by that method. Significantly, flame sprayed brazing alloy coatings had the advantage of excellent retention on the sandwich faces during brazing. There was little "run-out" of the brazing alloys and filleting was uniform on both faces of the brazed sandwiches. The mechanical test data listed above and much of the sandwich test data reported within were derived from fluxless brazed sandwich specimens, having the brazing alloy placed by oxy-acetylene flame spraying it onto the sandwich facing sheets.

During the second year of the contract, additional brazing alloy tests were conducted to roll clad brazing alloy foils onto substrates, to utilize powdered brazing alloys, and to obtain the No. 719 alloy in the form of foil. In addition, tooling and heat treating methods were investigated to determine the manufacturing feasibility for quenching large, honeycomb core sandwich brazements. Successful brazing and heat treating of X7005 and X7106 were demonstrated using the No. 719 brazing alloy in the form of 0.005" foil. Their respective facing tensile properties were the following:

Sandwich Facing Material 0.062" Thick	Tensile Strength psi	Yield Strength psi	Elongation Per Cent
X7005	50,000	44,000	10
X7106	53,000	48,000	4

The third year of the contract was devoted primarily to brazing alloy development. Alloy X7106 was brazed with two newly developed brazing alloys: one in the system Al-Ge-Si-Zn; and the other, in the system Al-Ge-Si-Ag. Sandwich facing tensile properties were the following:

Sandwich Facing Material 0.062" Thick	Brazing Alloy	Tensile Strength psi	Yield Strength psi	Elongation Per Cent
X7106	Al-Ge-Si-Zn	54,500	47,000	5
X7106	Al-Ge-Si-Ag	57,000	55,000	2

Although quenching rates and aging heat treatments qualify the various data listed above, it is apparent that brazed X7005 and X7106 honeycomb core sandwich panels can be produced with sandwich facings tensile yield strengths of about 44,000 and 48,000 psi respectively, and 5% tensile elongation. The advantages of the newly developed fluxless brazing alloys (Al-Ge-Si-Zn or Al-Ge-Si-Ag) over brazing alloys No. 716 or No. 719 was their lower brazing temperature, with their correspondingly lower diffusion rates into alloy X7106.

2. SANDWICH PANEL BRAZING AND TESTING PROGRAM

2.1 BRAZED AND AIR QUENCHED X7005, X7106, AND 7039

Based on the results of brazing alloy screening tests and brazing alloy development (Volume I), the selection of brazing alloys and facing materials for scale-up manufacturing presented the following possibilities (during the first year of the program):

(1) Braze clad 6951 (713 or 714 brazing alloy) offering a yield strength of about 20 to 25 KSI when air quenched.

(2) Braze clad X7005 (718 brazing alloy) offering a yield strength of about 35 KSI when air quenched. However, availability to meet schedule was questionable and X7005 honeycomb core could not be used because 718 dissolved thin foils of X7005.

(3) Intermediate brazing alloy foils positioned between sandwich face and core. However, only 718 brazing alloy foil would be available. The 719 alloy had never been rolled, and the 716 alloy was available only in limited quantities of 0.10" thickness. This would restrict facing material choice to X7005, but X7005 core could not be used.

(4) Flame sprayed brazing alloy placement using brazing alloys 719 and/or 716. Facing materials might be X7005, X7106, or 7039. The core could be X7005 or 6951. However, flame sprayed brazing alloy placement had obvious disadvantages. It could not be used on thin faces, distorts thick or preformed faces, uniformity of deposit cannot be assured, and oxide inclusions would be present both within the deposit and at the interface between the deposit and the face sheet. Contrasted with the disadvantages, were the excellent appearance and test results of experimental panels (Volume I

Before making the brazing alloy decisions, additional tests were run. Sheet material of X7005, X7106 and 7039 were heat treated together in air ½ hour at 900°F, air quenched to room temperature, then aged 24 hours at room temperature, followed by 48 hours at 250°F.

The following data were obtained:

Specimen	Gage Inch	UTS KSI	YS 0.2% Offset KSI	Elongation Per Cent
X7005	0.040	43.6	31.4	11.5
X7005	0.063	41.1	30.2	12.5
X7106	0.062	54.5	43.6	15.0
7039	0.061	54.8	41.4	12.5

The strength levels for X7005 were lower than those obtained by air quenching from the brazing temperature, indicating defective heat treatments.

The tests were repeated on X7005 and X7106 using 1 hour at 900°F, air quenched to room temperature, then aged 7 days at room temperature followed by 48 hours at 250°F.

The following data were obtained:

Specimen	Gage Inch	UTS KSI	YS 0.2% Offset KSI	Elongation Per Cent
X7005	0.040	45.9	36.4	13.0
X7005	0.063	46.1	37.6	13.7
X7106	0.062	51.4	38.2	14.0

From these data, it was concluded that X7005, X7106, and 7039 would be the optimum sandwich panel facing materials at this point in the program. The brazing alloys selected were 719 and 716, placed on the sandwich faces by flame spraying them from 1/8" diameter wire. Table I lists the materials combinations, the number of panels brazed, and their brazing method.

The discussion on brazing the individual panels follows:

Table 1

PANELS FABRICATED

Code	Material	Brazing Alloy and Placement*	Brazing Method	Panel Size
A	62 Mil X7005 Facings and Type 6-80 Core**	719	Electric Blanket	28" x 40" x 0.6" Thick
B	62 Mil 7106 Facings 6951 Type 6-80 Core	716	Electric Blanket	28" x 40" x 0.6" Thick
C	62 Mil 7039 Facings 6951 Type 6-80 Core	719	Electric Blanket	28" x 40" x 0.6" Thick
AA	62 Mil X7005 Facings and Type 6-80 Core	719	Furnace	28" x 40" x 0.6" Thick
BB	62 Mil 7106 Facings 6951 Type 6-80 Core	716	Furnace	24" x 40" x 0.6" Thick
CC	90 Mil 7039 Facings 6951 Type 6-80 Core	719 core to facing	Furnace	24" x 40" x 0.6" Thick
	62 Mil X7106 Edge Member	716 metal to metal		

*Brazing alloys were flame sprayed except the 716 alloy used for metal to metal edge members

**Hexagonal cell type on all panels except B and BB which had square cell core type

2.1.1 Braze Tooling, Methods, and Results

The brazing tool selected for the first three large, flat panels is shown in Figure 1. It had been used to braze PH series steel panels followed by aging at 1070°F. Inasmuch as the 1070° aging temperature was within the aluminum alloy brazing range, time-temperature plots of aging treatments were reviewed for temperature profiles across the panels. Based on the steel panel aging plots, temperature control and uniformity were thought to be satisfactory for the aluminum panels. It was noted, however, that to maintain control, heating rates were slow. It was planned to accelerate the overall cycle for aluminum brazing.

Panel Assembly

The sandwich panel detail parts were assembled in flat retorts fabricated from low carbon steel. The retort faces were 0.015" thick and 'U' section edges were 0.025". Included in the retort were stainless steel blocks, accurately machined to the thickness of the sandwich panel. The blocks support the load of the upper half of the brazing die. The retort and a portion of the assembled parts are shown in Figure 2.

No flux nor stop-off was used. All of the assembled parts were either clean steel or aluminum. The steel parts were cleaned by sand blasting. The aluminum alloy facing sheets were sandblasted (one side) prior to flame spraying the brazing alloys, then the back side was scrubbed with acetone, but the flame sprayed surface was untouched.

Brazing Alloy Placement

The brazing alloys, in the form of 1/8" dia. wire, were flame sprayed onto panel faces using a Metco 'Y' gun, modified to incorporate an electric drive mechanism. Spraying conditions were adjusted to deposit a coarse, clean coating. The conditions were: acetylene 41CFH, oxygen 84CFH (as calculated from standard Metco flow meters), air blast pressure 70 psi, and a wire feed rate of 66 inch/minute. The amount of wire sprayed was premeasured and cut to spray 6 feet of wire/square foot of panel area, resulting in a deposit whose thickness varied from 0.010" to 0.012".

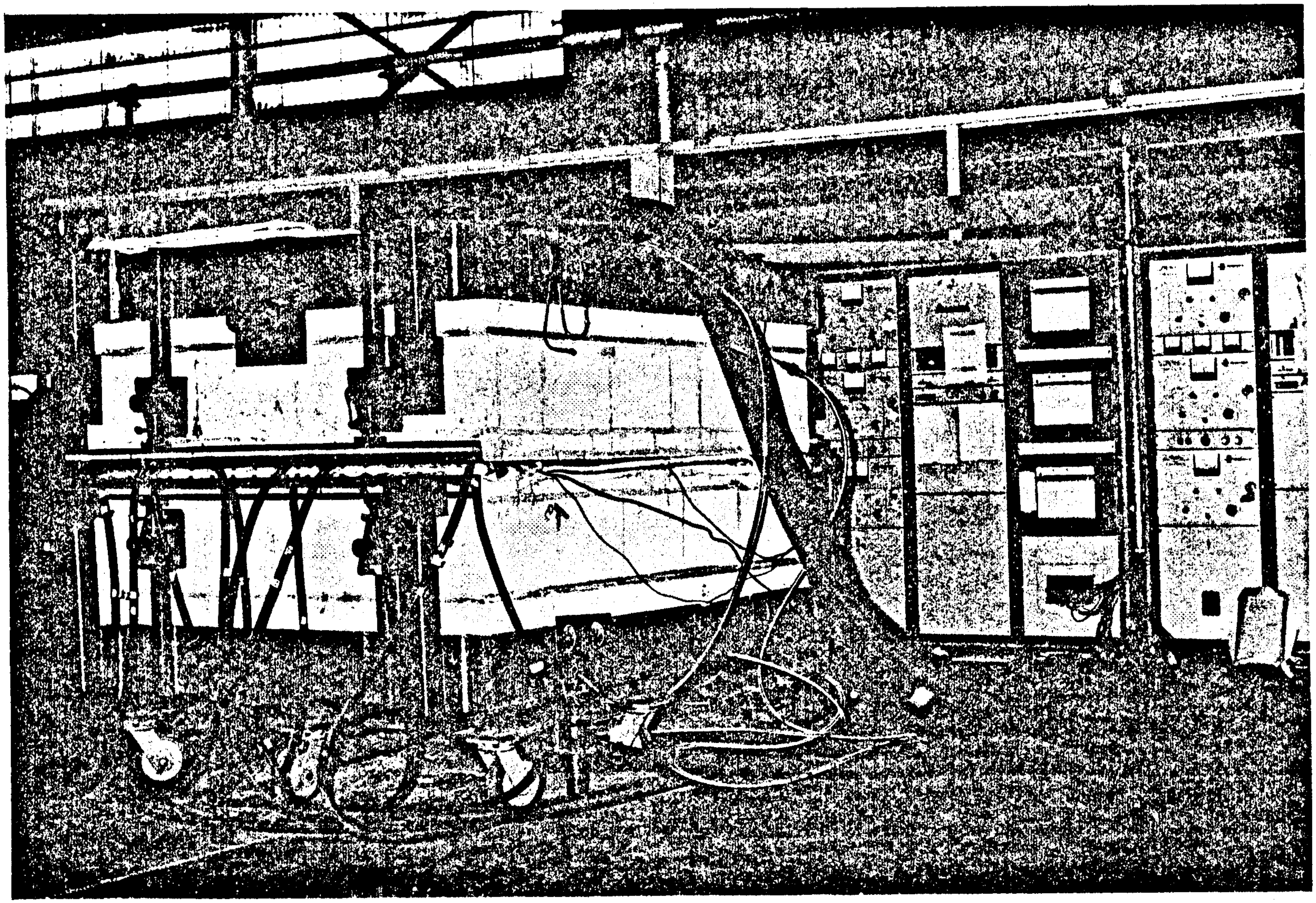


Figure 1 Glasrock Blanket Brazing Tool, 5' x 9' in Size, Employing External Strip-Type Heating Elements and Plenum Chambers for Forced Air and Cryogenic Nitrogen Cooling through Ports in the Tool Faces.

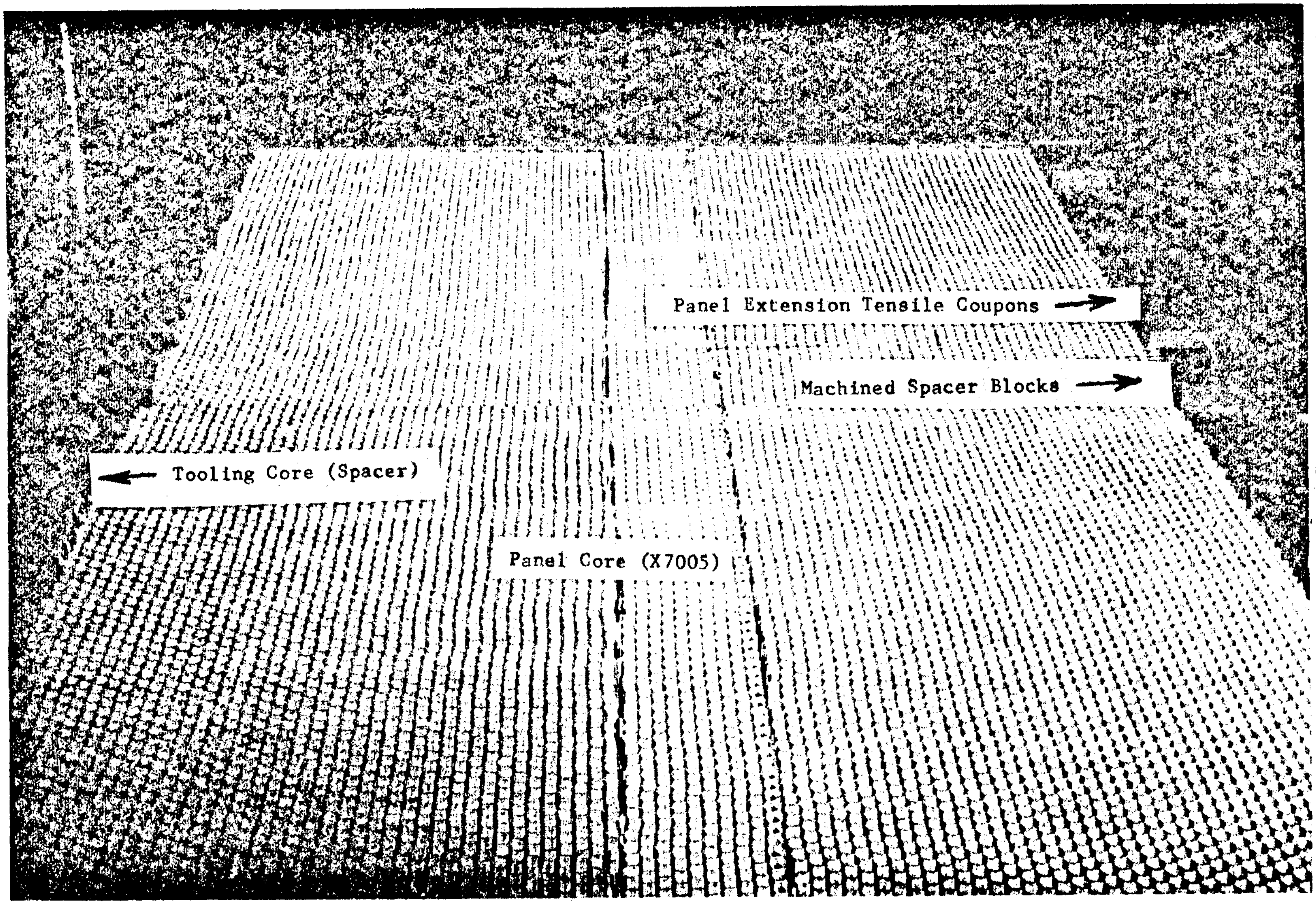


Figure 2 Partial Assembly in Retort of Detail Parts of Aluminum Sandwich Panel A.

Brazing Method

Panels A, B, and C were assembled and brazed by almost the identical procedures. Retorts were sealed by welding, then leak tested and purged. Purging involved ten cycles of evacuation and back filling with argon. Retort placement on the blanket brazing tool is shown in Figure 3. Fiberglass cloth positioned around the retort served two purposes. It electrically insulated the retort from the heating elements and was packed around the panel to prevent heat loss. The specified brazing cycles and actual temperatures are listed below:

Panel No.	Brazing Alloy	Specified Time and Temperature	Actual Brazing Temperature
A	719	10 min. 1040-1050°F	1010-1050°F
B	716	10 min. 1075-1080°F	1050-1080°F
C	719	10 min. 1050-1060°F	1040-1060°F

Note: Panel C was specified after Panel A was examined.

The brazing time-temperature cycles which were achieved differed from the specified temperatures. An excessive temperature spread for Panels A and B was most probably caused by high heating rates. Panel C was heated more slowly and the temperature profile showed better control.

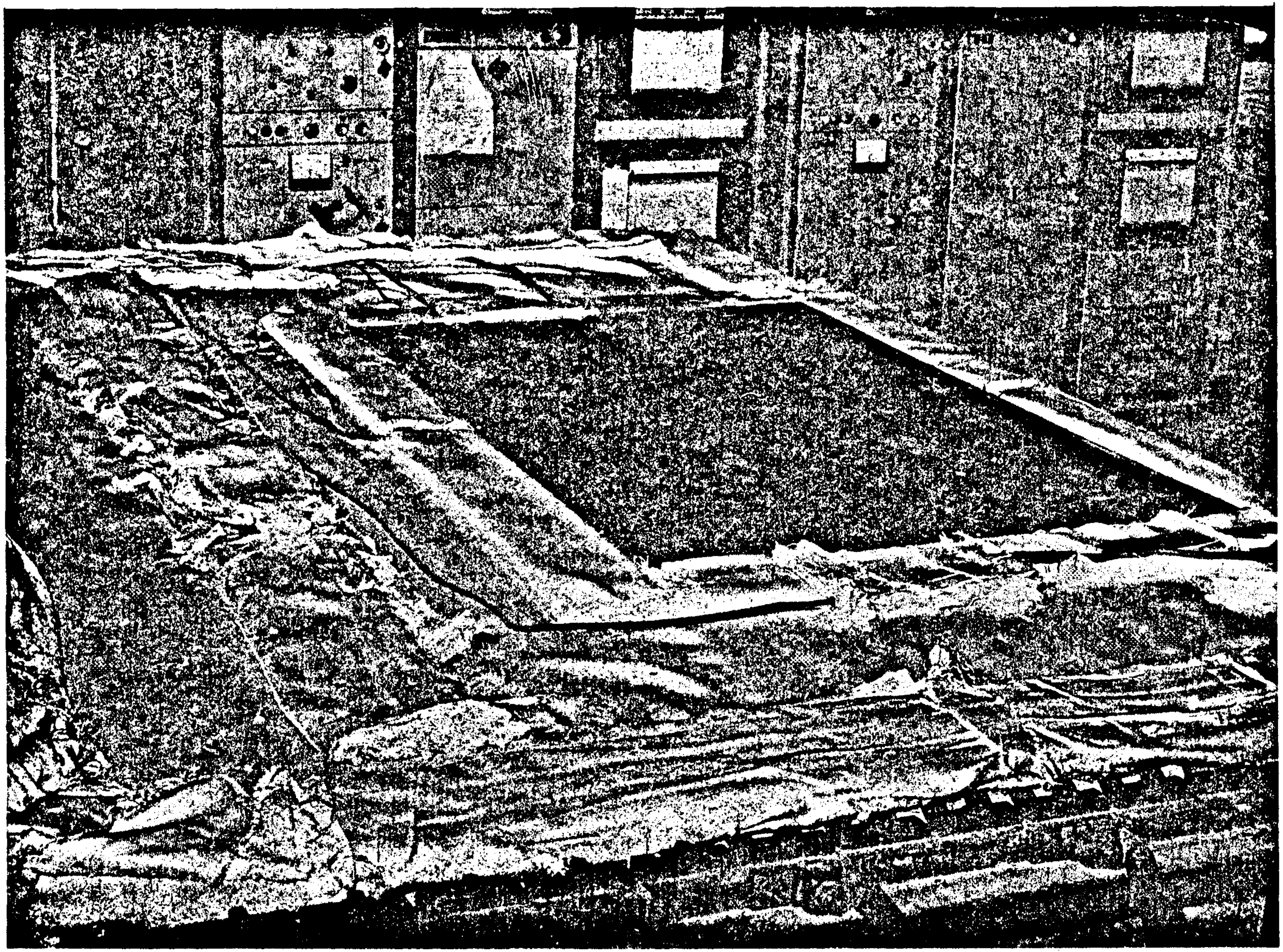


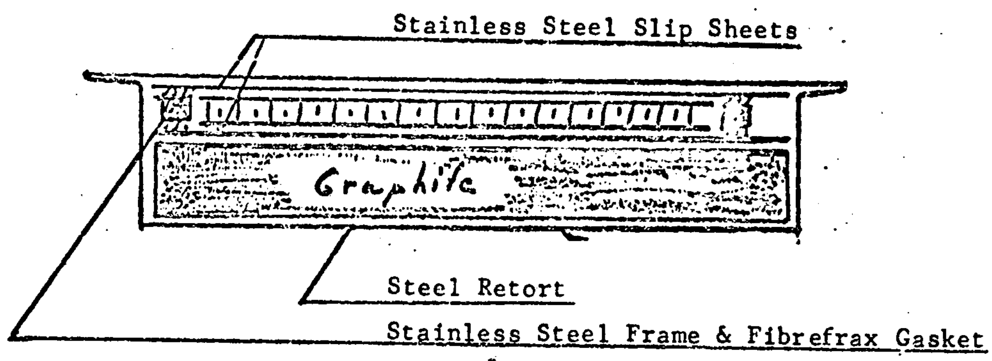
Figure 3 Retort Placement on Bottom Half of Blanket Brazing Tool.

The decision was made that three additional panels would be brazed by furnace brazing.

Panel AA was assembled like Panel A. No fixturing nor external tooling for flatness was employed. The retort was positioned on the furnace grate and the grate was brought up into the circulating air furnace which had been pre-heated to 1100°F. The brazing temperature was 1060 $\pm$ 10°F.

Panels BB and CC were furnace brazed in a different type of retort and their size was smaller, measuring 24" x 40".

A schematic of the retort cross section and panel assembly is shown below:



The brazing temperature for Panel BB was 1080° $\pm$ 10°F and for Panel CC, it was 1070° $\pm$ 10°F.

Tooling Pressure

Face-to-core contact pressure was provided by the retort faces as a result of a partial pressure within the retort. The atmospheric clamping pressures used for the various panels are listed below:

A	0.3 psi
AA	0.4 psi
B	0.2 psi
BB	0.2 psi
C	0.2 psi
CC	0.2 psi

No core buckling occurred as a result of these pressures.

Panel Heat Treatments

The quenching of Panels A (X7005), B (X7106), and C (7039) was done in the brazing tool at an average rate of 20°F/min., which had been shown to be too slow for X7106 and 7039. Also, the furnace brazed panels AA, BB, and CC, were cooled at rates too slow; consequently, all panels except A were post-braze heat treated.

Panels B, C, AA, and BB were heat treated together, 1 hour at 900°F, then air quenched. The quenching rate was only about 30°F/min.

Panel CC was post-braze heat treated, separately, in a laboratory furnace, after having been cut into small specimens. The quenching rate was approximately 100°F/min. The solutioning temperature was 750° to 800°F for 1 hour.

Aging heat treatments were as follows:

Panels A, AA, B and BB: 7 days at room temperature followed by 48 hours at 250°F.

Panels C and CC: 2 days at room temperature followed by 16 hours at 180° and 12 hours at 300°F.

BRAZED PANEL ANALYSES AND DISPOSITION

The several characteristics of the six brazed panels are listed in Table 2, followed by discussions of the individual panels.

Radiographic and Ultrasonic Inspection

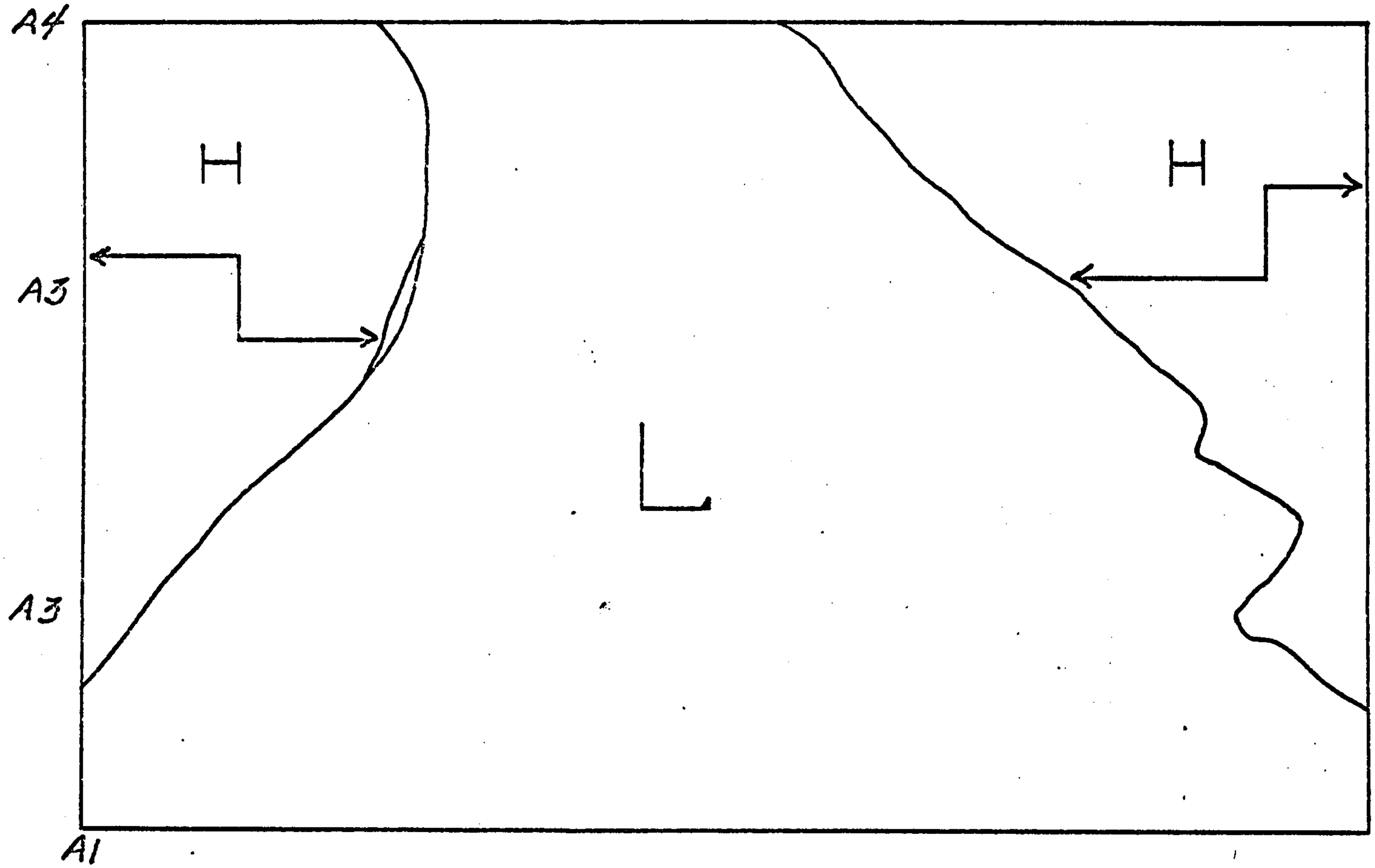
Panel A

The radiographic report for Panel A is shown in Figure 4 and the ultrasonic inspection record, Figure 5, agreed almost exactly with the radiographic report except for the following important deviation. Areas shown as light fillets on the radiograph were shown as voids on the ultrasonic report. The top and bottom of the panel were nearly identical. Based on the two inspection reports, specimens were laid-out and numbered as shown in Figure 6. The large areas not divided into specimens, were reserved for further examination. Pending the test results, the panel appeared to be adequately brazed on three edges; on the fourth edge, the thermocouple indicated a temperature less than specified, and that edge appeared to be poorly brazed.

Table 2

CHARACTERISTICS OF BRAZED PANELS

Code	Dimensional Inspection	Braze Quality	Remarks
A	(Measured Values) Flat within 0.020"	2/3 of the panel acceptable	
B	Flat within 0.060"	2/3 of the panel acceptable	
C	Flat within 0.040"	Poor	Fully brazed, but the brazing alloy was incompletely melted
AA	(Qualitative Determination) Maximum Warpage Approx. 1/2"	100% brazed	Panel air cooled in a free retort - No hard tooling employed
BB	Local Buckle from Tooling Restraint, otherwise flat	90% brazed	
CC	Flat	100% brazed	The brazing temperature was too high. Excessive diffusion of brazing alloy into the panel faces resulted.



H - Heavy Fillets

L - Denotes Light to Possibly Non-Existing Fillets

PA1666-1
S/N A
ACN 141-3

Figure 4 Radiographic Inspection Report on Panel A. Panel A had X7005 Faces and Core and 719 Brazing Alloy. It was Brazed in a Flat Blanket Brazing Die.

NOT REPRODUCIBLE

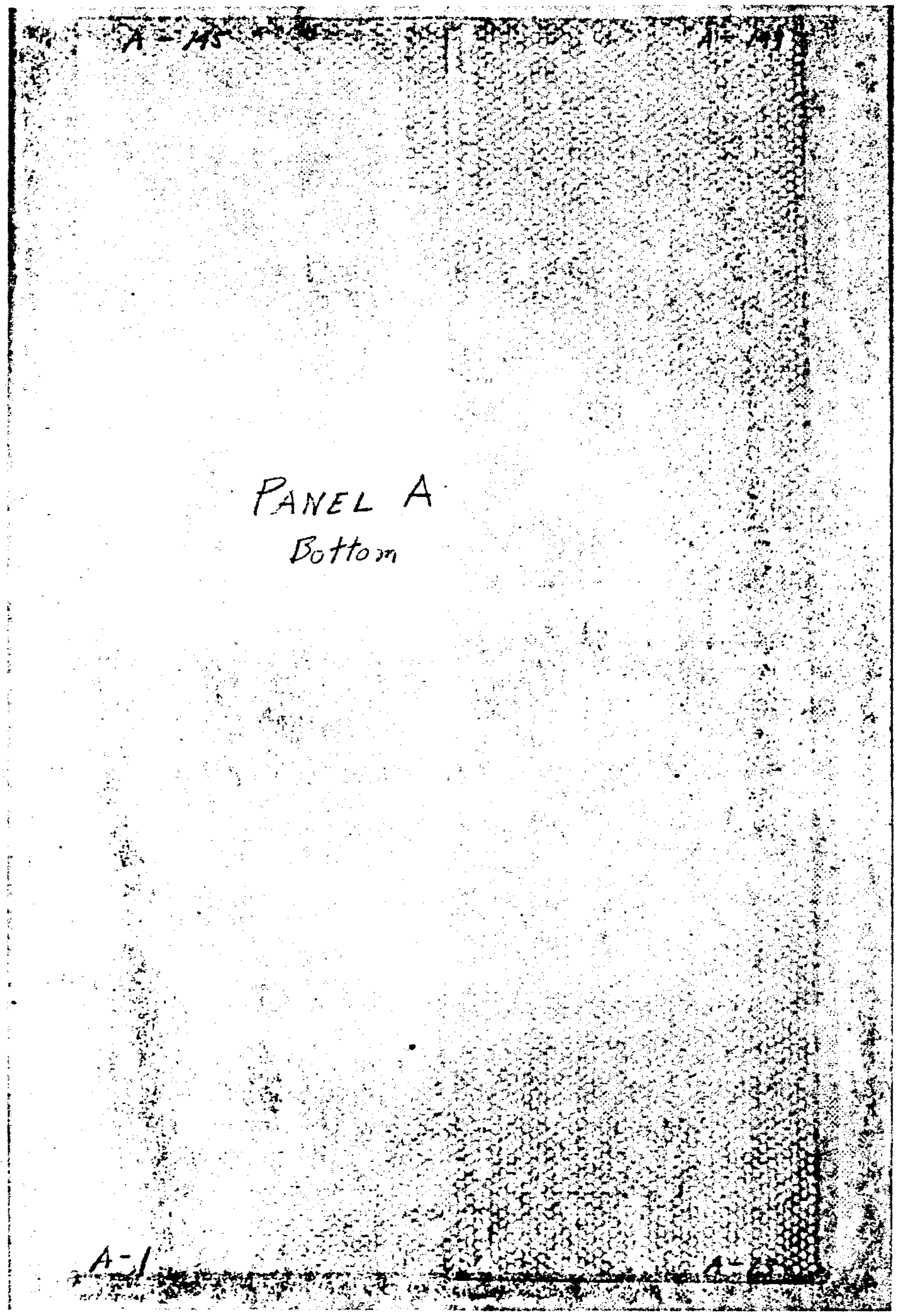


Figure 5 Ultrasonic Inspection Report of One Face of Panel A. Panel A had X7005 Faces and Core and 719 Brazing Alloy. It was Brazed in a Flat Blanket Brazing Die.

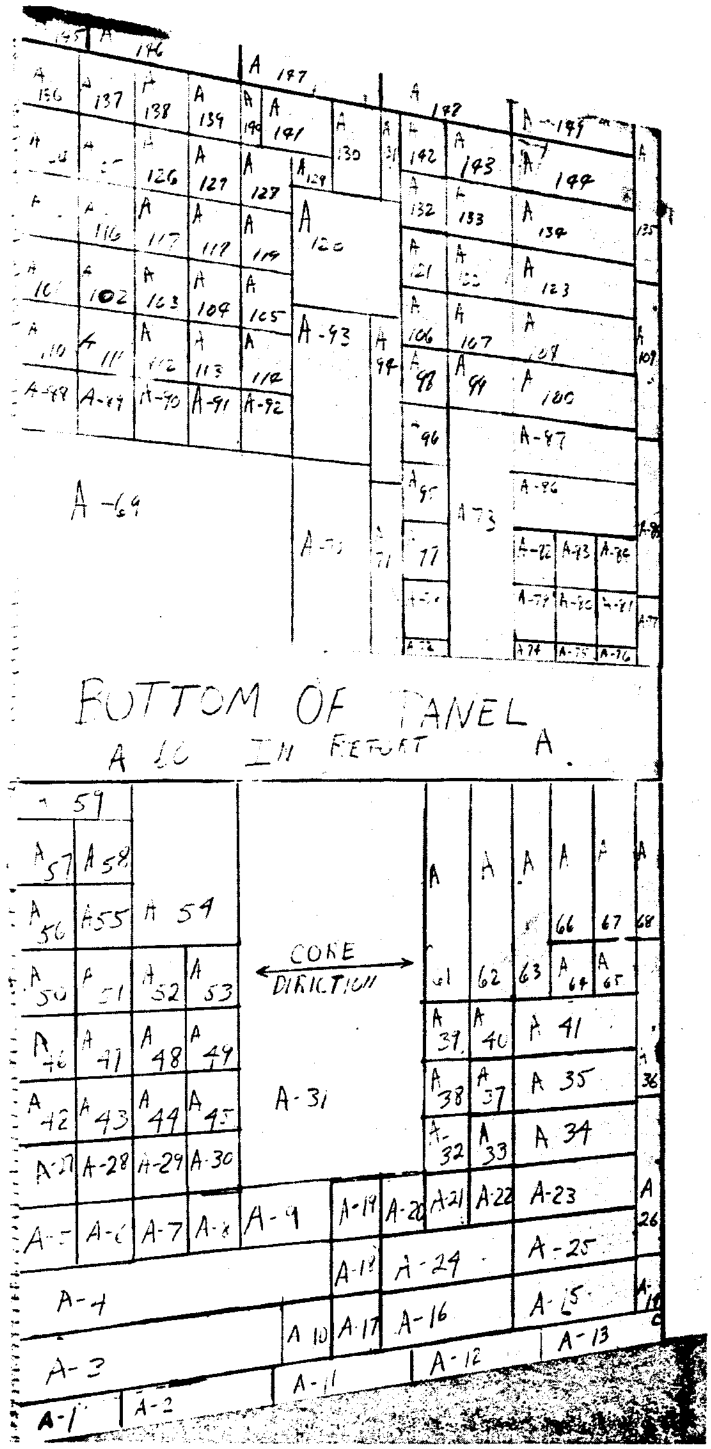


Figure 6 **Lay-out of Test Specimens on Panel A. Panel A had X7005 Faces and Core and 719 Brazing Alloy. It was Brazed in a Flat Blanket Brazing Die.**

Apparently the brazing temperature profile across the panel was much like the inspection report drawing of Figure 4, where only two large corners reached the appropriate brazing temperature.

Panel AA

The radiographic inspection report is shown in Figure 7. Based on that report and on visual inspection, it was concluded that Panel AA was completely brazed. Ultrasonic inspection was not done. The panel was dividied into test specimens as shown in Figure 8.

Panel B

The radiographic report was almost identical to that of Panel A. Also, the ultrasonic inspection report, Figure 9, was almost identical to that of Panel A except that poorly brazed areas appeared dark, rather than light.

Destructive testing revealed a poor core-to-face attachment in those dark areas because the brazing alloy had not fully melted. The brazing alloy was detected, ultrasonically, as a solid sheet.

Specimen lay-out on Panel B is shown in Figure 10.

Panel BB

Radiographic inspection was not accomplished. The ultrasonic inspection report is shown in Figure 11. The ultrasonic inspection report of the top face showed void areas corresponding to local face buckling. Specimen lay-out is shown in Figure 12.

Panel C

Based on visual examination of the panel and retort it was concluded that there had been a leak in the retort or gas line and that the panel ultimately would be scrapped. Radiographic inspection confirmed a complete lack of large fillets. Some small fillets were thought to be visible in the

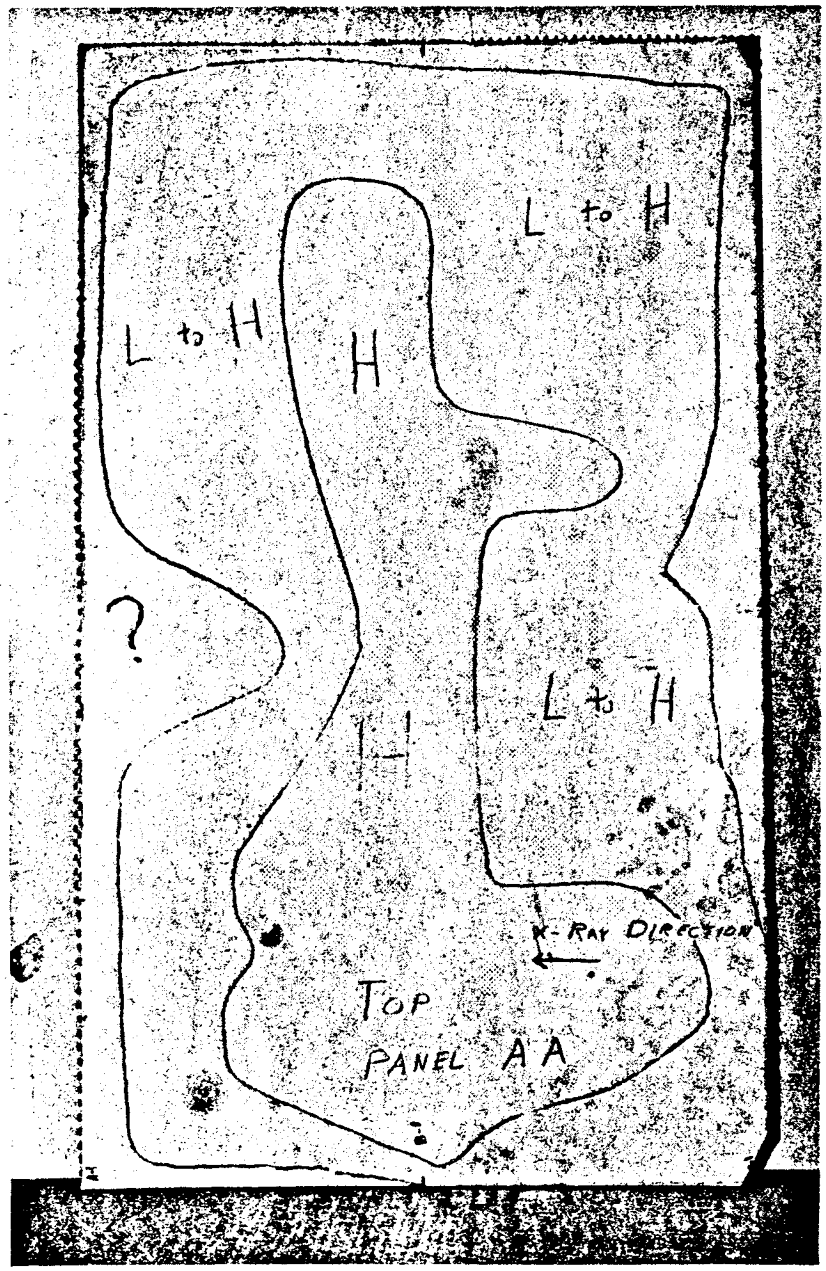


Figure 7 Radiographic Inspection Report Plotted on Panel AA.

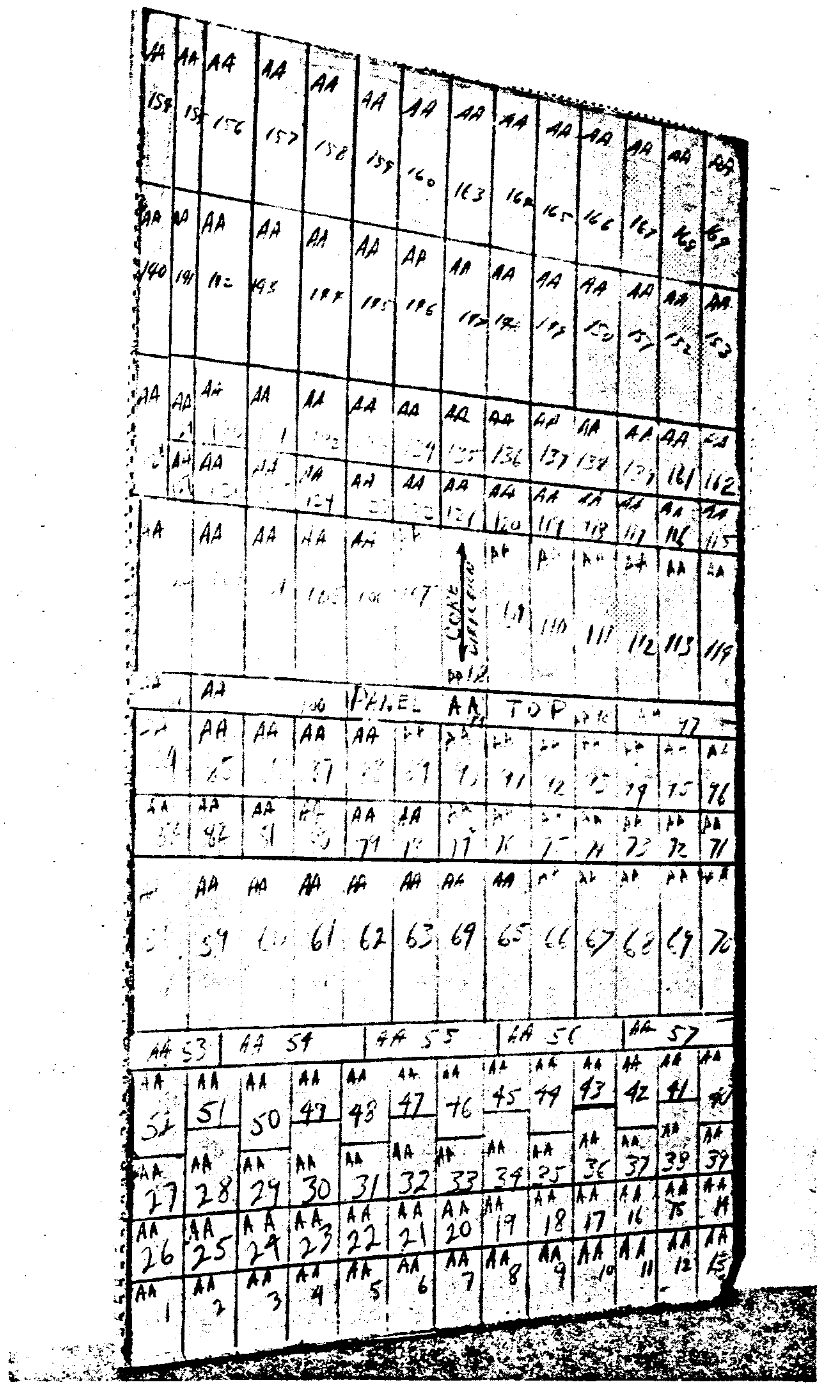


Figure 8 Lay-out of Test Specimens on Panel AA. Panel AA had X7005 Faces and Core and 719 Brazing Alloy. It was Furnace Brazed.

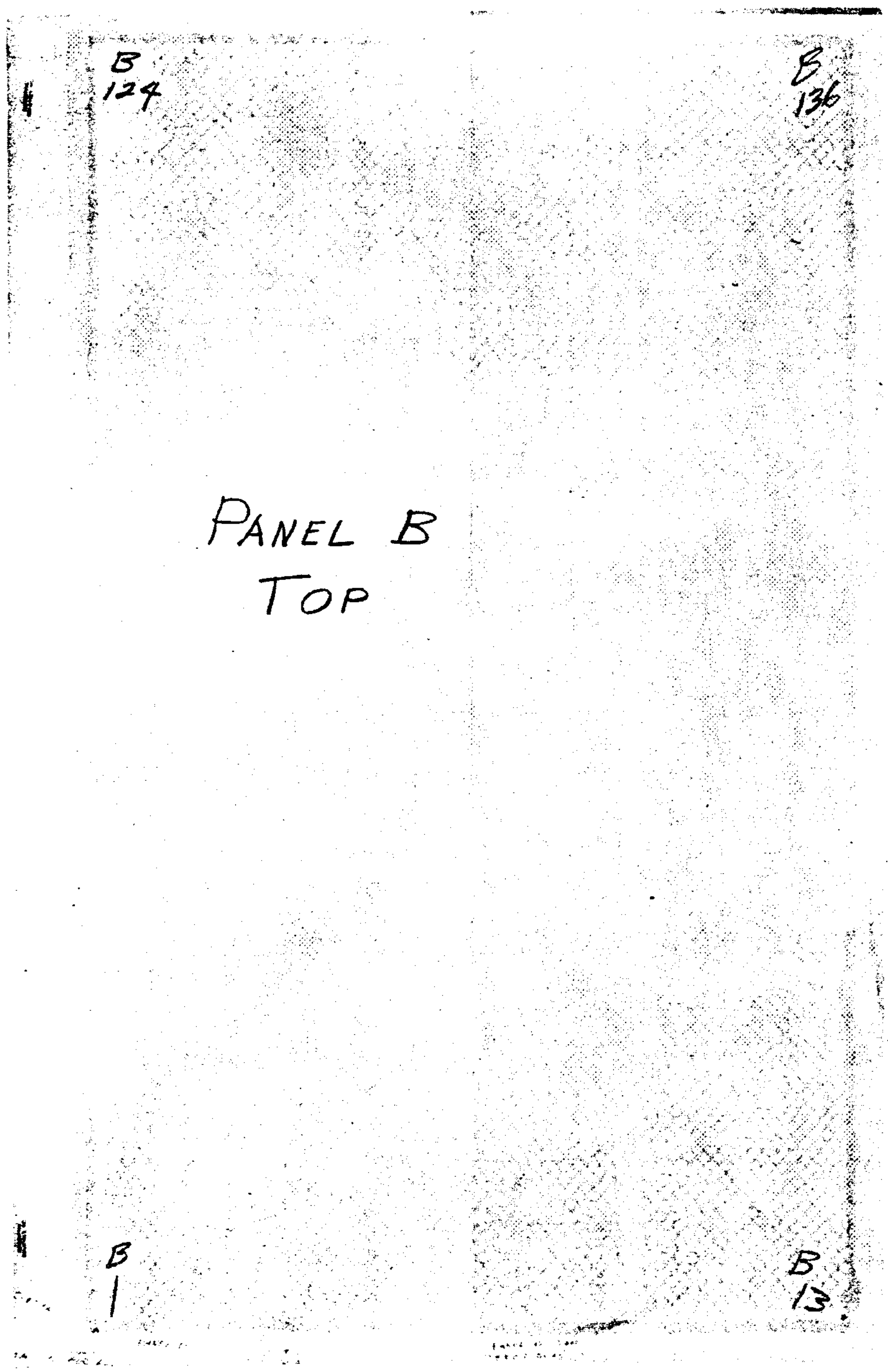


Figure 9 Ultrasonic Inspection Report of One Face of Panel B. Panel B had X7106 Faces, 6951 Core and 716 Brazing Alloy. It was Brazed in a Flat Blanket Brazing Die.

NOT REPRODUCIBLE

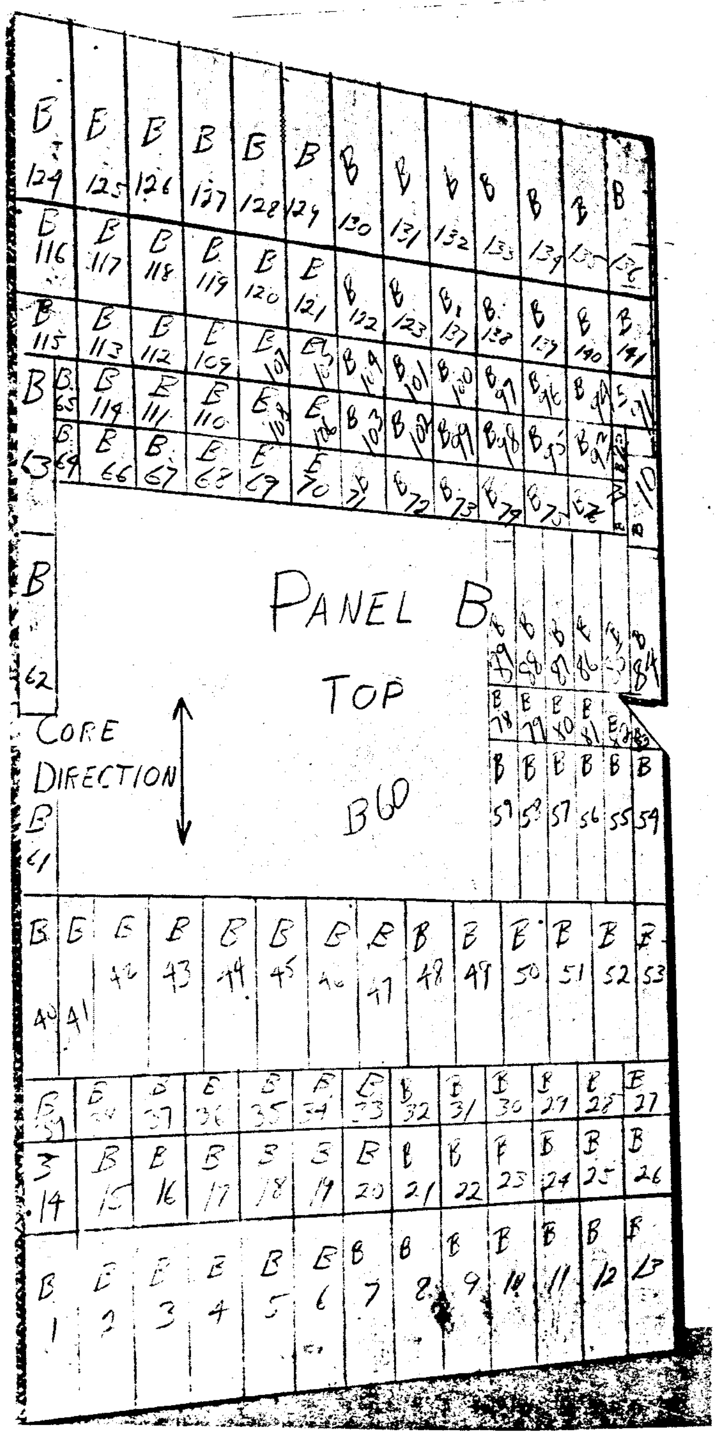


Figure 10 Lay-out of Test Specimens on Panel B. Panel B had X7106 Faces, 6951 Core and 716 Brazing Alloy. It was Brazed in a Flat Blanket Brazing Die.

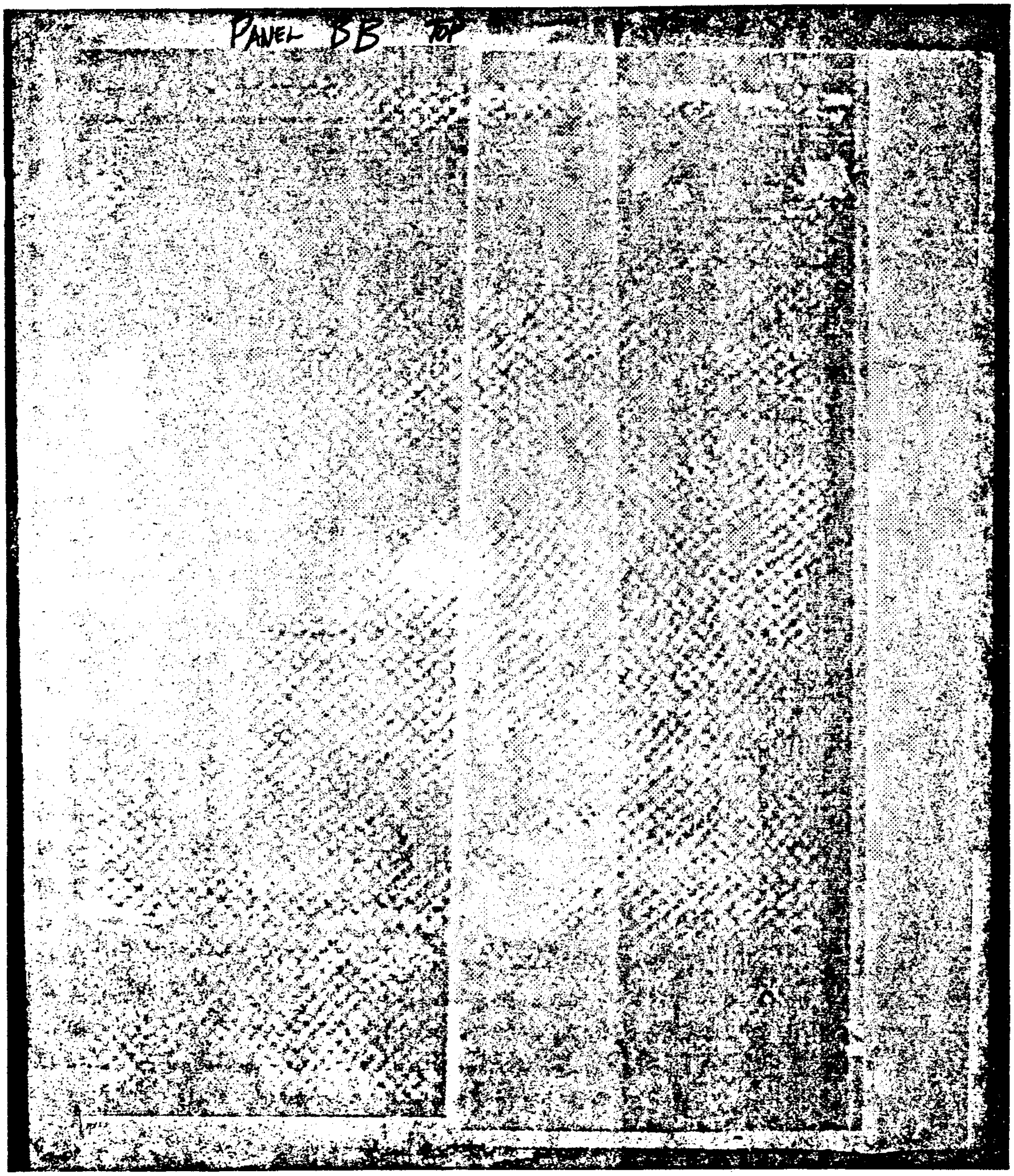


Figure 11 Ultrasonic Inspection Report of Top Face (in Retort) of Panel BB. Panel BB had X7106 Faces, 6951 Core and 716 Brazing Alloy. It was Furnace Brazed.

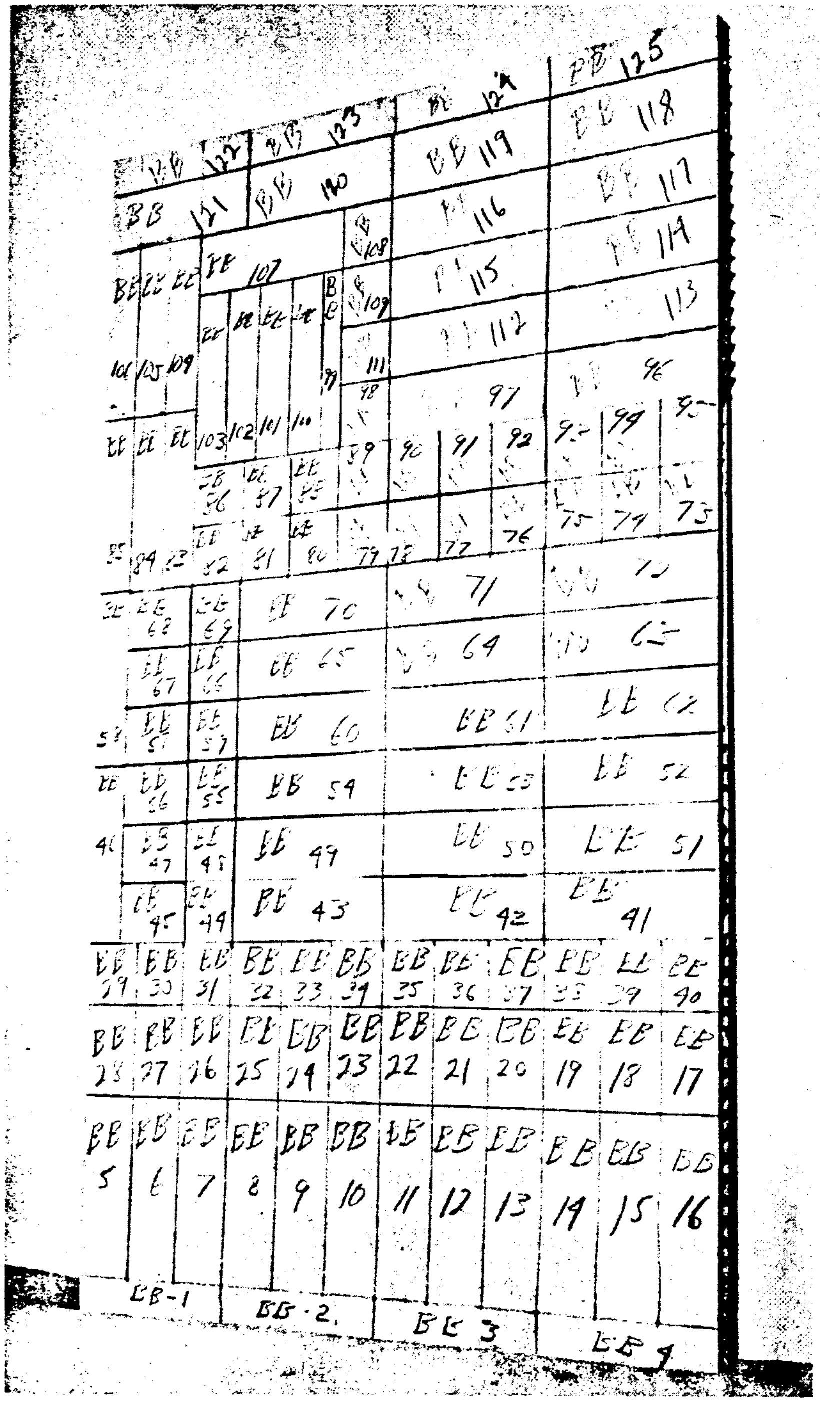


Figure 12 Lay-out of Test Specimens on Panel BB. Panel BB had X7106 Faces, 6951 Core, and 716 Brazing Alloy. It was Furnace Brazed.

radiograph. The panel was not ultrasonically inspected. Sectioning of the panel, however, indicated fair core-to-face attachment. The panel faces could not be separated from the core manually. Therefore, specimen lay-out was made as shown in Figure 13.

The core pattern on the panel (Figure 13) is termed 'growth marks'. These marks are caused by abrasion between the panel and retort faces, which are the resultant effects of differing expansion rates. This is often, but not necessarily, associated with a good braze. The marks also can be brought out by rubbing a sandwich panel with a piece of wood or plastic.

Panel CC

Panel CC differed from the other panels because of materials availability and by the inclusion of simulated edge members. The materials difference was the substitution of 0.090" thick faces rather than 0.062" faces as had been used on the other panels.

Edge members were 0.062" thick X7106 formed in an 'L' section, which simulated half of a 'Z' section.

The brazing alloy for edge member 'A' was 0.010" thick 716 alloy. A strip of 0.001" copper foil was added also to promote flow. Edge member 'B' had only the 0.010" thick 716 alloy added. To eliminate core splices, the panel was divided into three parts with the edge members on the central part. The ultrasonic inspection report of the bottom face is shown in Figure 14. The panel apparently was fully brazed, but the top face inspection report showed random discontinuties. Radiographic inspection was not accomplished, except for edge members, which are shown in Figures 15 and 16. The top face of the panel was too hot during brazing, as was clearly shown by the brazing alloy penetration of that face. The bottom face was apparently satisfactory.

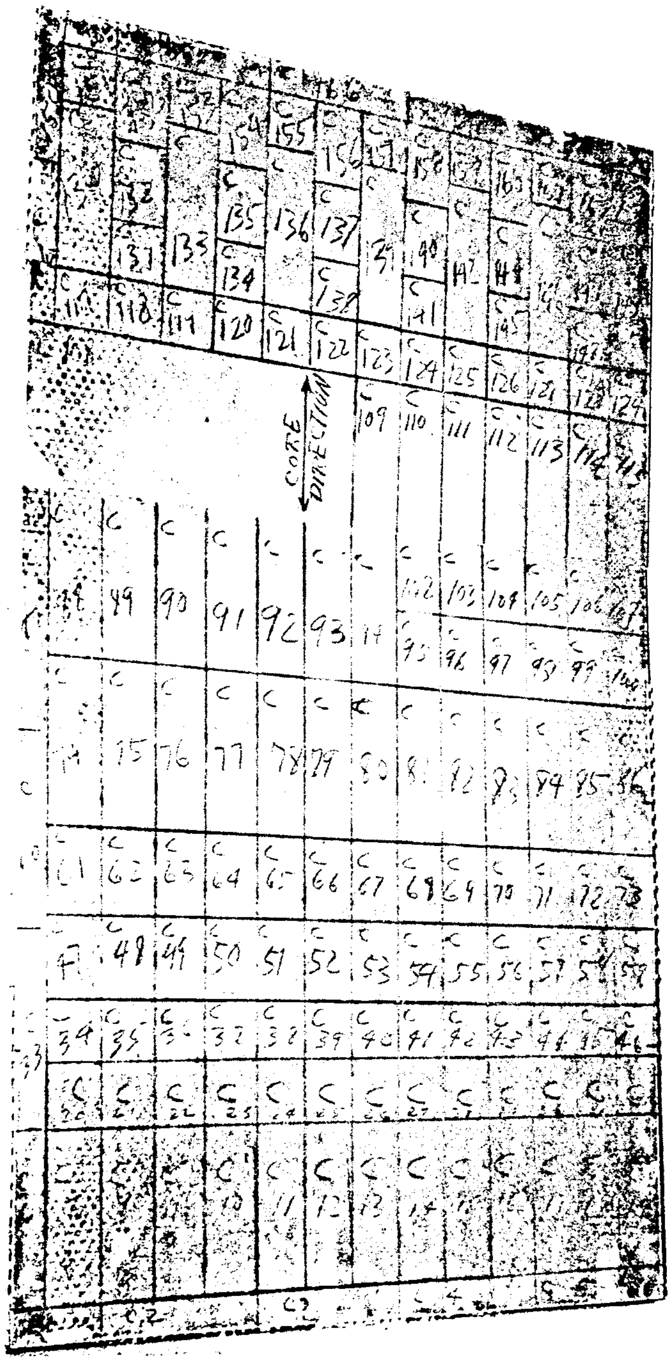


Figure 13 Lay-out of Test Specimens on Panel C. Panel C had 7039 Faces, 6951 and 719 Brazing Alloy. It was Brazed in a Blanket Brazing Tool.

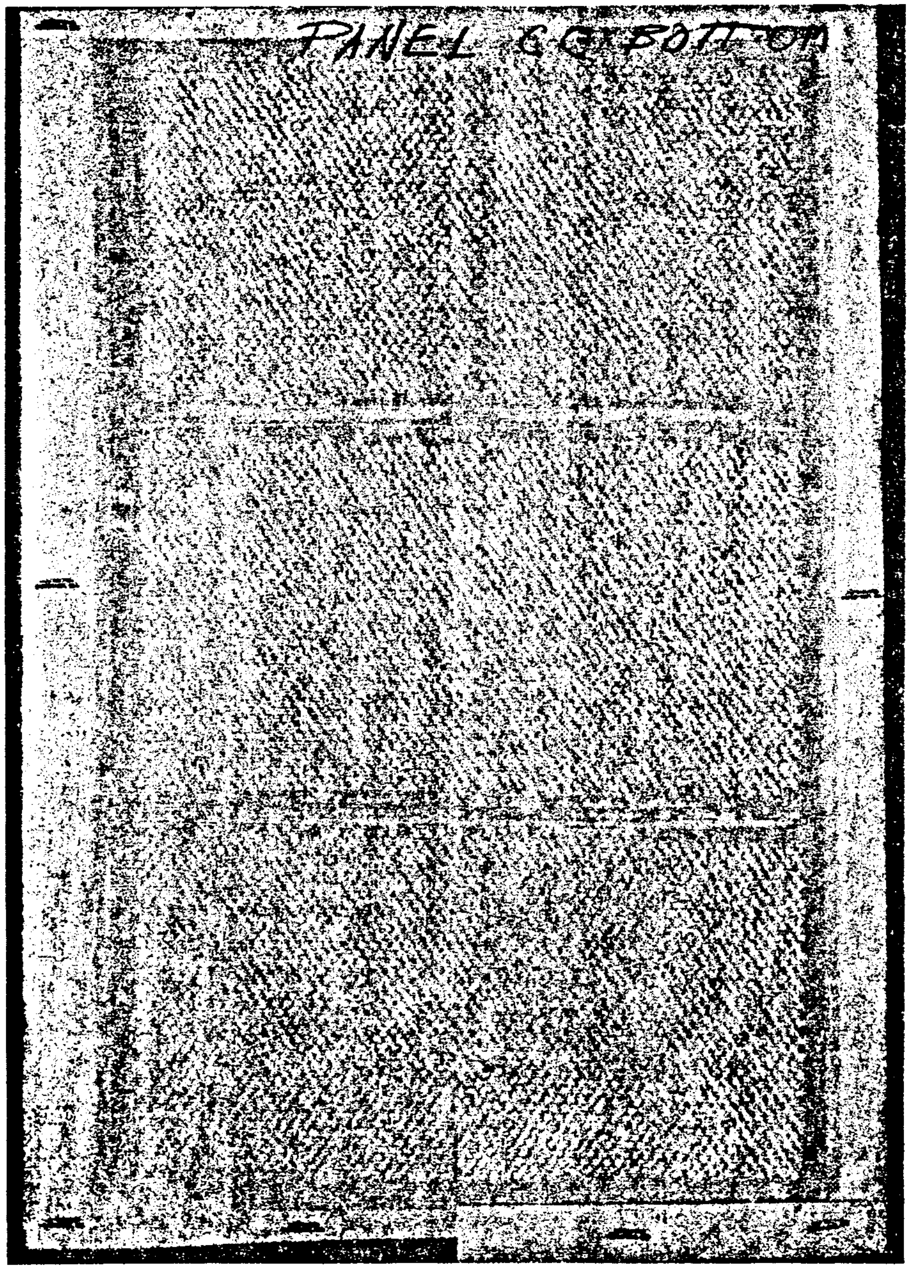


Figure 14 Ultrasonic Inspection Report of Bottom Face (in Retort) of Panel CC. Panel CC had 7039 Faces, 6951 Core, 719 Brazing Alloy, and a Section of it had Edge Members. It was Furnace Brazed.

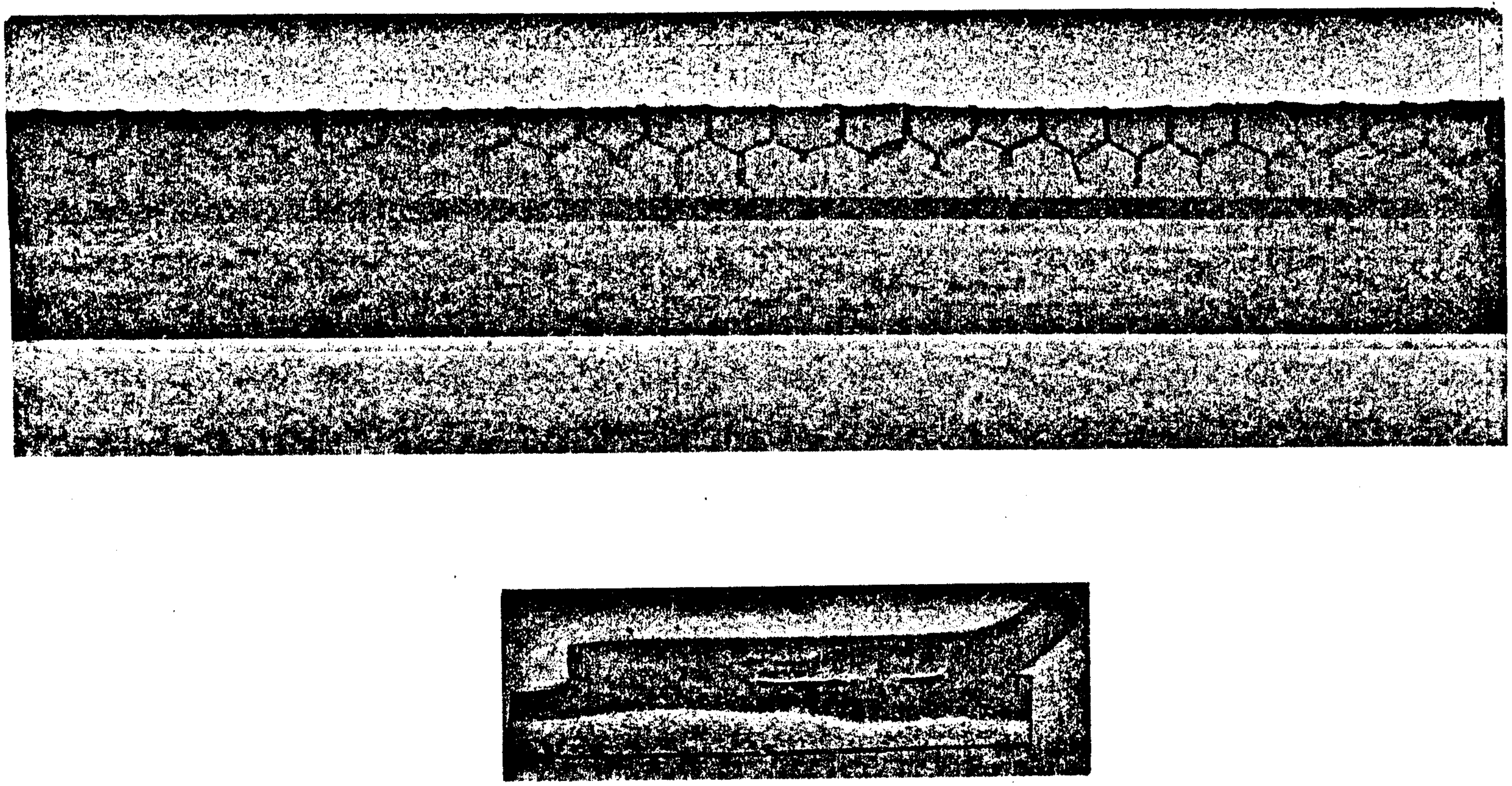


Figure 15 Top: Radiograph of a Portion of Panel CC Edge Member A, Comprised of an .090" 7039 Face and an .062" X 7106 L Member. Brazing Alloy was .010" 716 and .001" Copper.

Bottom: Cross Section Photomacrograph of Edge Member A Showing Voids Caused by Copper and Showing the Extent of Brazing Alloy Diffusion into Faying Surfaces.

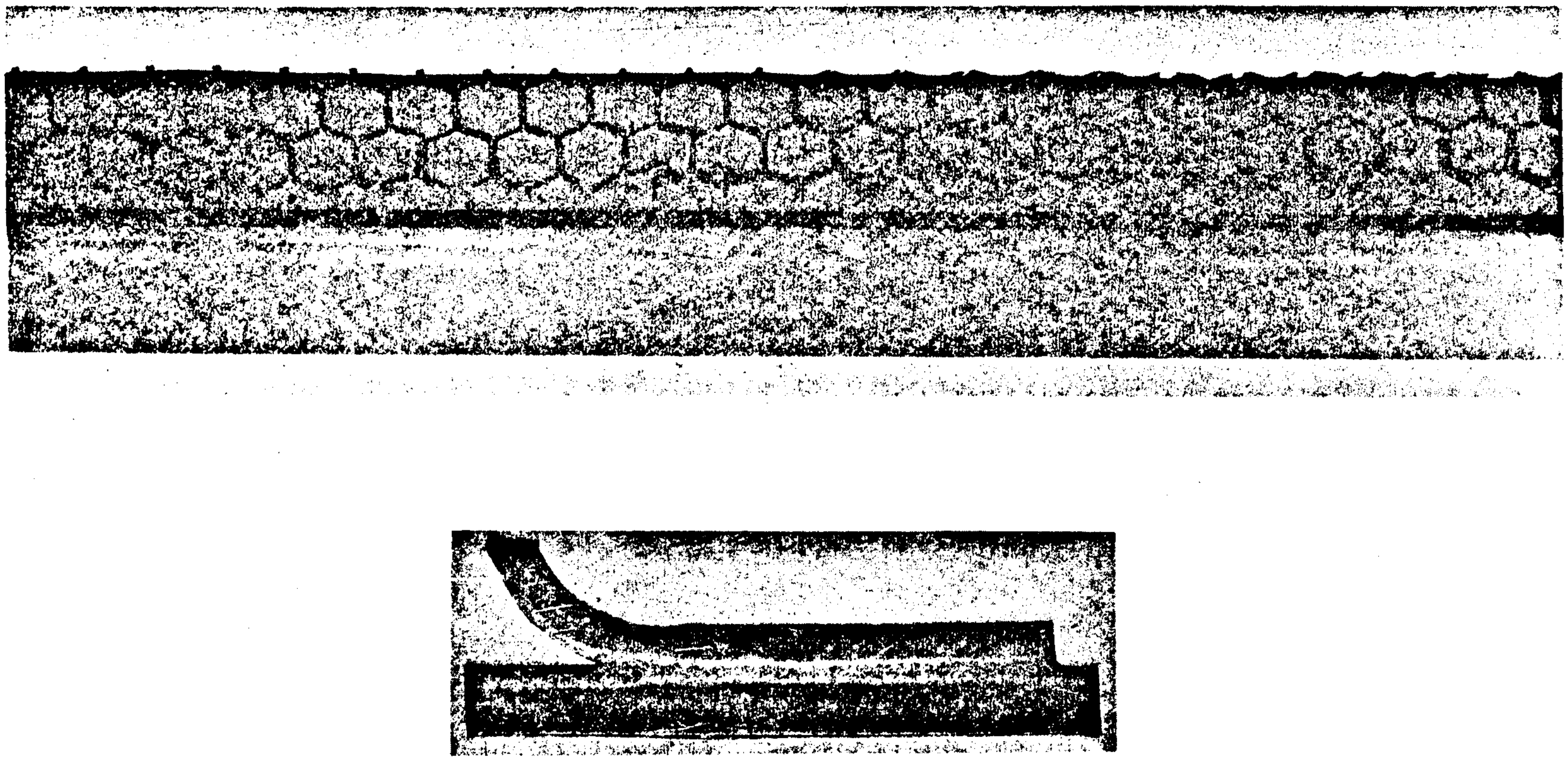


Figure 16 Top: Radiograph of a portion of Panel CC Edge Member B, Comprised of an .090" 7039 Face and an .062" X7106 L Member. Brazing Alloy was .010" 716.

Bottom: Cross Section Photomacrograph of Edge Member B showing Few Voids in the Brazed Joint and Showing Extent of Brazing Alloy Diffusion into Faying Surfaces.

Metallographic Examination

Panel A had small fillets as shown in Figure 17. However, there was evidence of incomplete brazing alloy melting, which would be expected from the brazing temperature profile. There was evidence of oxide inclusions in the brazing alloy, but the interfaces were free of oxides in all areas where brazing alloy flow occurred.

A section of Panel AA is shown in Figure 18. The higher brazing temperature contributed to better flow than that obtained on Panel A. The 719 braze alloy had no adverse effect on the X7005 faces. No diffusion or grain growth was evident. The thin X7005 core roots evidenced some brazing alloy diffusion and grain growth.

Brazing alloy 716 on Panel B was not fully melted, as shown by Figure 19. The brazing alloy had no effect on the 6951 core, but diffused into the X7106 substrate to a depth of approximately 0.010". Some core-to-face attachment was evidenced, but the braze was not satisfactory. Panel BB was brazed at a higher temperature and was sufficiently brazed as shown in Figure 20. On the other hand, the brazing alloy (716) diffused into the X7106 faces 0.020" to 0.040" causing probable incipient melting and grain growth. There was little or no effect by the brazing alloy on the 6951 core roots.

Panel C showed a poor braze throughout (Figure 21) and the brazing alloy appeared to be incompletely melted. No diffusion into the Panel C substrate was noted. However, Panel CC, brazed at a higher temperature, evidencing substantial brazing alloy diffusion into the faces as was shown in the photomacrographs, Figures 15 and 16. The top face had local brazing alloy penetration entirely through the face.

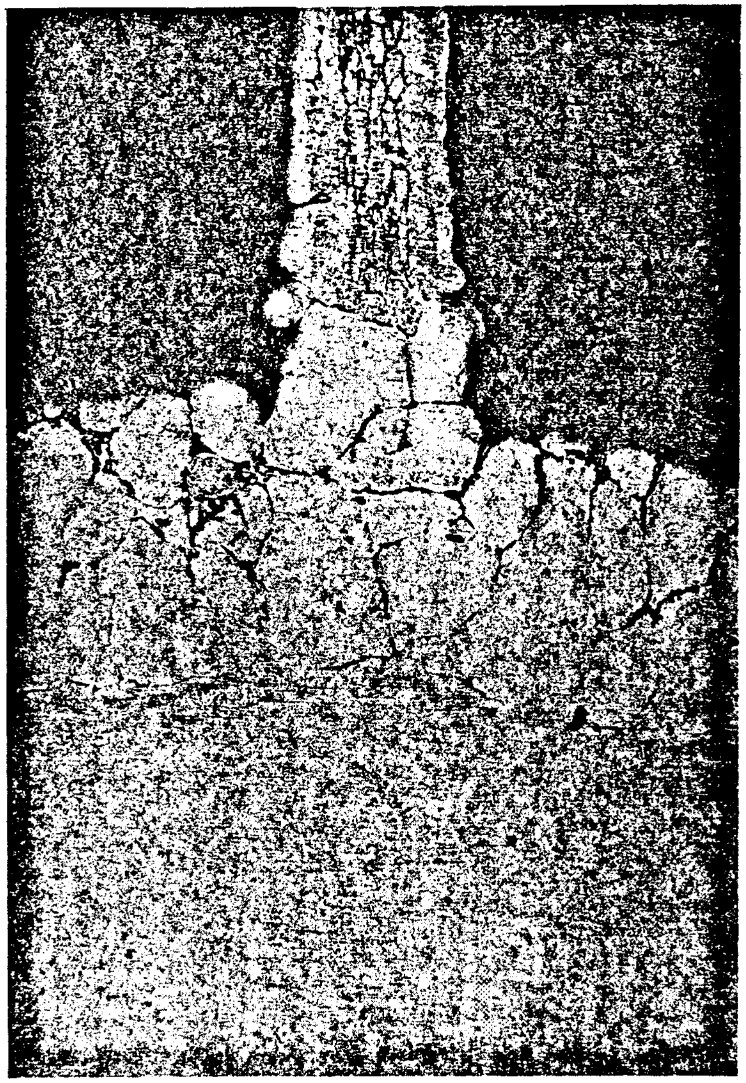


Figure 17 Cross Section Photomicrograph of Core-to-Face Joint of Panel A. Faces and Core were X7005. Brazing Alloy was 719.

Mag: 100X
Etchant: Flick's

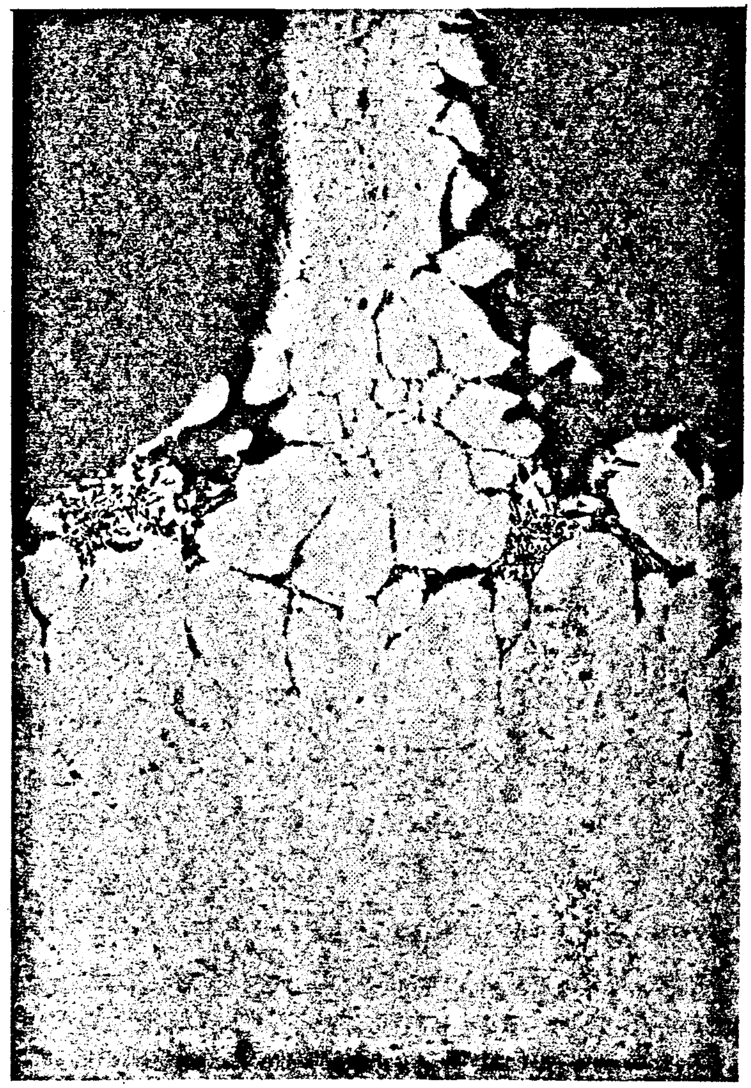


Figure 18 Cross Section Photomicrograph of Core-to-Face Joint of Panel AA. Face and Core were X7005. Brazing Alloy was 719.
Mag: 100X
Etchant: Flick's

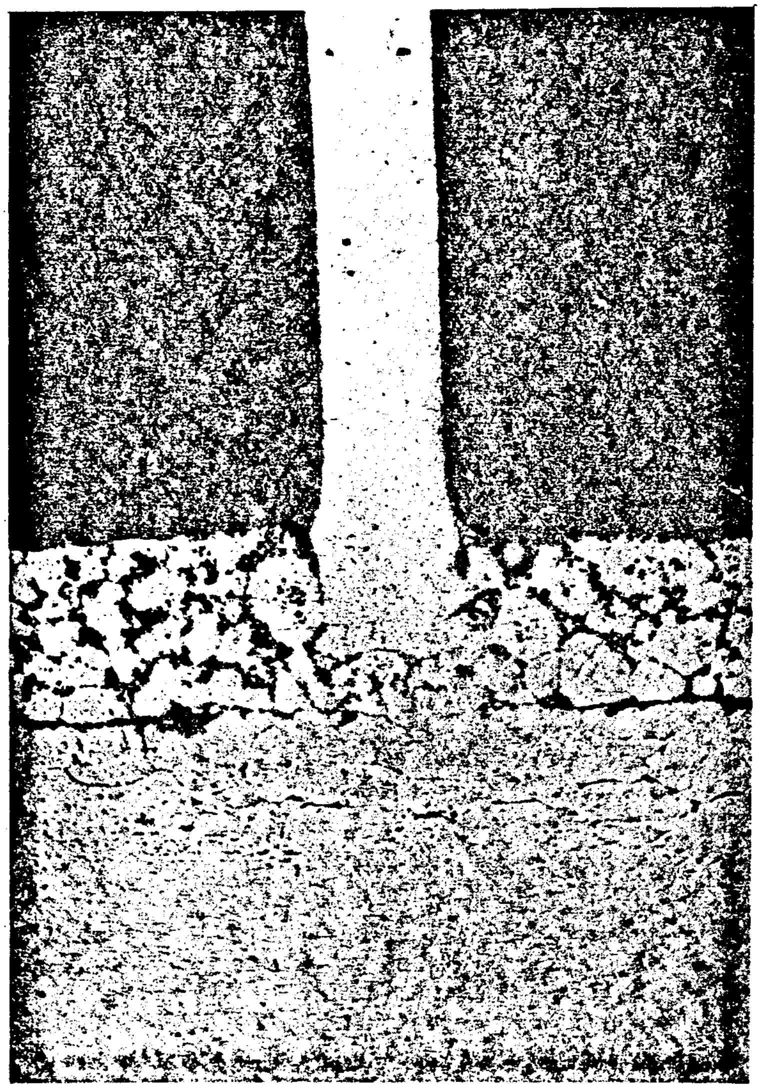


Figure 19 Cross Section Photomicrograph of Core-to-Face Joint of Panel B. Faces were X7106 and Core was 6951. Brazing Alloy was 716.
Mag: 100X
Etchant: 2%HF

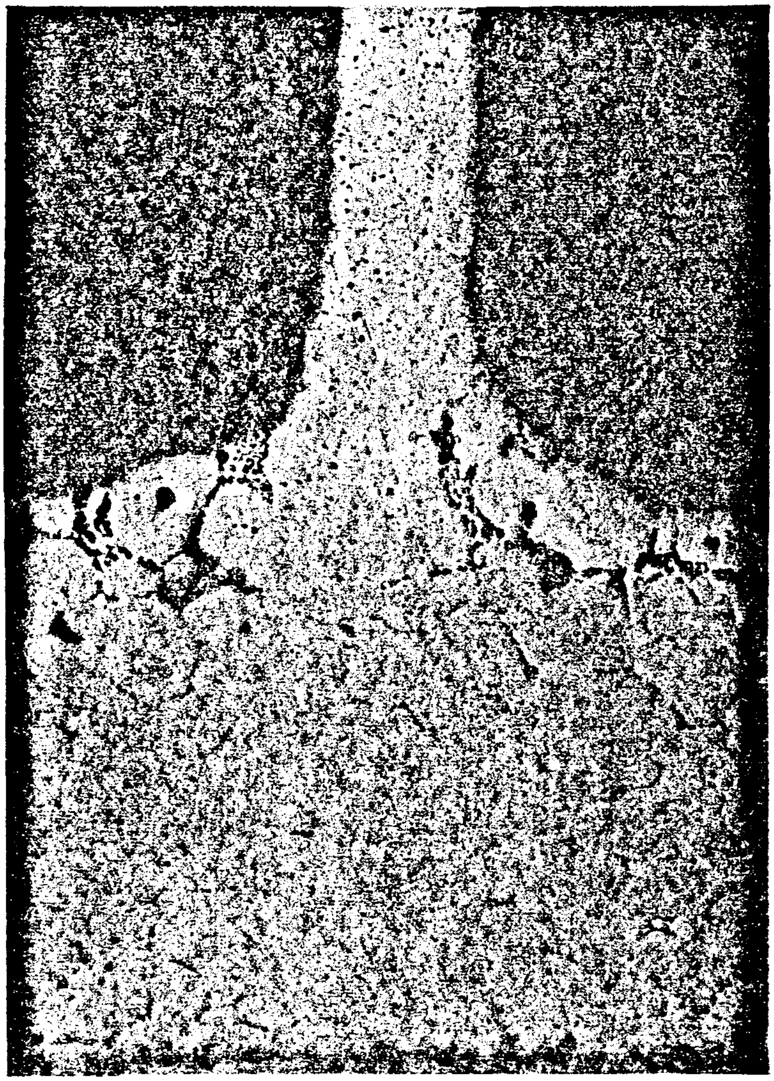


Figure 20 Cross Section Photomicrograph of Core-to-Face Joint of Panel BB. Faces were X7106 and Core was 6951. Brazing Alloy was 716.

Mag: 100X
Etchant: 2% HF

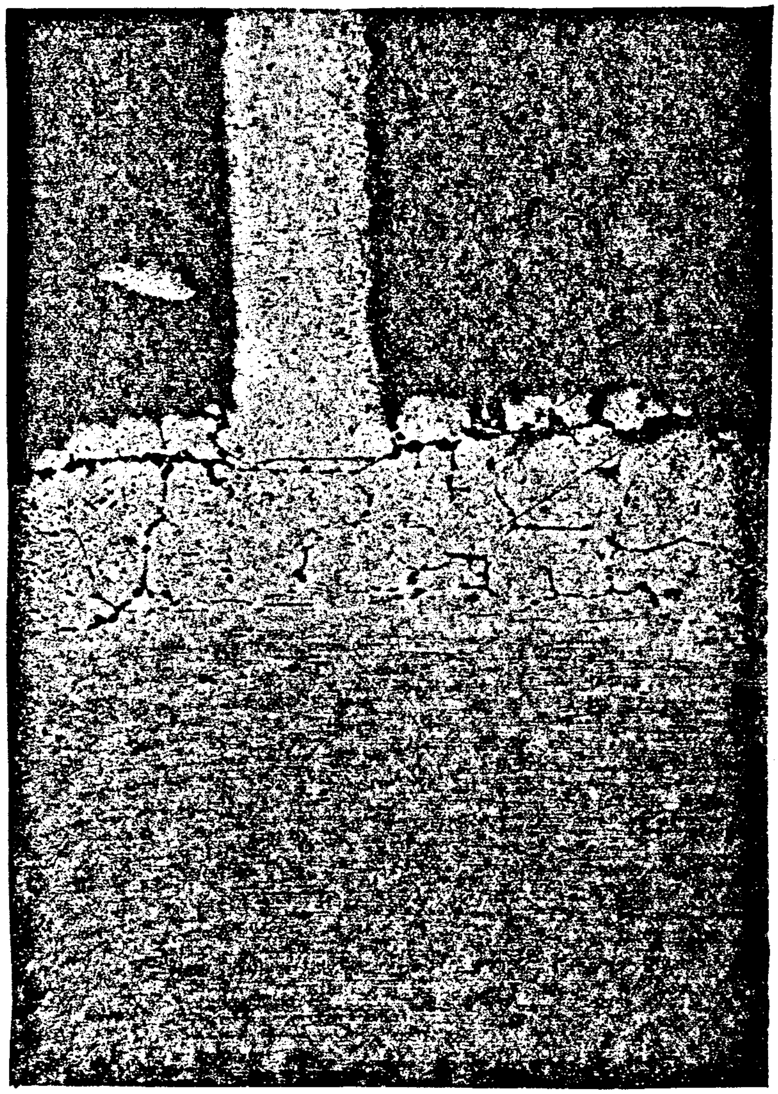


Figure 21 Cross Section Photomicrograph of Core-to-Face Joint of Panel C. Faces were 7039 and Core was 6951. Brazing Alloy was 719.
Mag: 100X
Etchant: Flick's

2.1.2 Testing Program

Scope

The following tests were conducted on each of the three brazed systems:

Tensile - panel faces

Tensile - panel extension (facing material without brazing alloy)

Flatwise Tensile - brazed sandwich

Flatwise Compression - brazed sandwich

Edgewise Compression - brazed sandwich

Plate Core shear - brazed sandwich

Flexure (short beam) - brazed sandwich

The tests were conducted at 600°F, 500°F, 200°F, room temperature, -100°F, -200°F, and -320°F at Aeronca and NASA*conducted tests at -423°F.

To provide reliable data, it was desired that 6 duplicate specimens be evaluated for each required test and temperature, which would have provided a total of 1008 individual tests. That goal was met, except for some instances, where there were an insufficient number of specimens available.

2.1.3 Data Presentation and Test Methods

The test data are summarized in Figures 22 through 29 and Tables 3 through 23 list each of the individual test specimens.

SUMMARY AND DISCUSSION OF TEST RESULTS

Panel Facing Tensile Data - Heat Treat Response and Effect of Brazing Alloys

The tensile data for X7005, Figure 22 , show that the room temperature minimums were met in all cases except for tensile elongation where brazing alloy coated X7005 was somewhat less ductile than bare X7005. The average

*Under the direction of Mr. O. Y. Reece.

quenching rate for X7005 was approximately 15°F to 20°F per minute.

Brazed X7106 and 7039 panels, Figures 23 and 24 were not quenched fast enough to develop full strength. In addition, their respective brazing alloys reduced their strengths by approximately 20%. Faster quenching rates and less agressive brazing alloys would be required to develop full mechanical properties of X7106 and 7039.

Edgewise Compression

The core stabilized the faces up to the ultimate compressive strength of the faces in most cases (Figure 25), except for Panels C and CC, where the large number of facing separations indicated poor braze quality.

Flatwise Tensile Strength

Figure 26 shows the spread in flatwise tensile data from the brazed panels, and Table 24 shows data from similar panels which were bonded with FM-1000 adhesive. The brazed and heat treated X7005 was consistently superior to the adhesive strength of bonded panels. The 6951 core brazed to X7106 was predominantly superior to the adhesively bonded panel, but overall, it was not brazed as well as the X7005 panel. Panels C and CC were poorly brazed but nevertheless, about half of the test values were equal to the values obtained from the adhesively bonded sandwich.

Flatwise Compression

The compressive strengths of the respective cores are summarized in Figure 27. Some room temperature design values from MIL-HANDBOOK-23, Part I, 5 October 1959, are given below for comparison:

Core Material & Type	Core Density	Compressive Strength psi
3003 H-19, ¼" cell .004" foil	7.68 lb./cu. ft.	625
3003 H-19, ¼" cell .005" foil	9.05	1,078
Stainless Steel, 17-7 PHA 3/8" Hex, bonded .002" foil	7.7	390
Stainless Steel, 17-7 PHTH-1050 ¼" square, welded .002 foil	7.8	705

Core Shear Stress

Figure 28 shows core shear strength both from the plate core shear tests and as calculated from the flexure tests. The correlation between the ranges of values from the two tests is reasonably good. For comparison, some design values from MIL HANDBOOK 23 are given below:

Core Material and Type	Core Density	Shear Strength psi W Direction	L Direction
3003 H-19, ¼" cell .004" foil	7.68 lb./cu. ft.	252	455
3003 H-19, ¼" cell .005" foil	9.05	304	527
Stainless Steel, 17-7 PHA 3/8" Hex, bonded .002" foil	7.7	145	315
Stainless Steel, 17-7 PHTH-1050 ¼" square, welded .002 foil	7.8	340	350

Core Shear Modulus

Shear modulus data are summarized in Figure 29. The correlation between plate core shear test values and flexure test values was not good, but the trends were consistent. Typical shear modulus data for the aluminum alloys 2003, 5052, 5056, 2024 were extracted from Hexcel Products, Inc., Technical Bulletin TSB120, and are listed below.

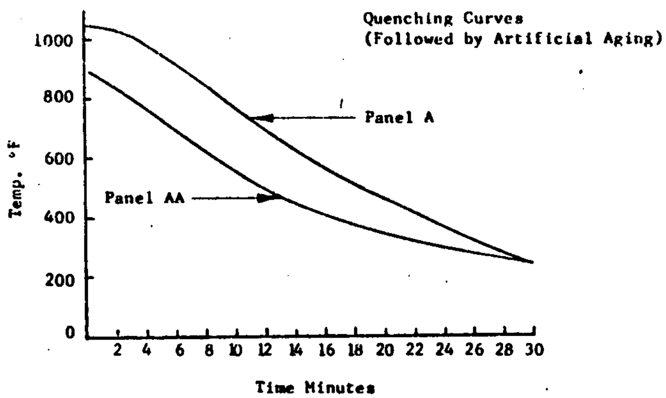
Core Density	Shear Modulus, psi W Direction	L Direction
7.0 lb./cu. ft.	50,000	105,000
8.0	55,000	125,000

Some design values from MIL HANDBOOK 23 are given below:

Core Material and Type	Core Density	Shear Modulus, psi	
		W Direction	L Direction
3003 H-19, ¼" cell .004" foil	7.68 lb./cu. ft.	37,000	84,000
3003 H-19, ¼" cell .005" foil	9.05	41,000	103,000
Stainless Steel, 17-7PHA 3/8" Hex, bonded .002" foil	7.7	29,000	74,000
Stainless Steel, 17-7PHT ¼" square, welded .002" foil	7.8	71,000	94,000

Data from plate core shear tests fall within the appropriate ranges, except that a few X7005 specimens (AA series) had particularly high values, which were readily correlated with heavy filleted areas on the inspection reports.

Panels A & AA
X7005, 0.063" Thick. Braze Coated Material had 719 Brazing Alloy.



Panel A was quenched from the brazing temperature.
Panel AA was post braze heat treated.

ALCOA Tentative Mechanical Properties, X7005-T6, Sheet, Plate & Extrusions, Room Temperature

Typical	
F_{tu}, ksi	51
F_{ty}, ksi	42
Elong. %	13

Minimum	
F_{tu}, ksi	45
F_{ty}, ksi	36
Elong. %	7

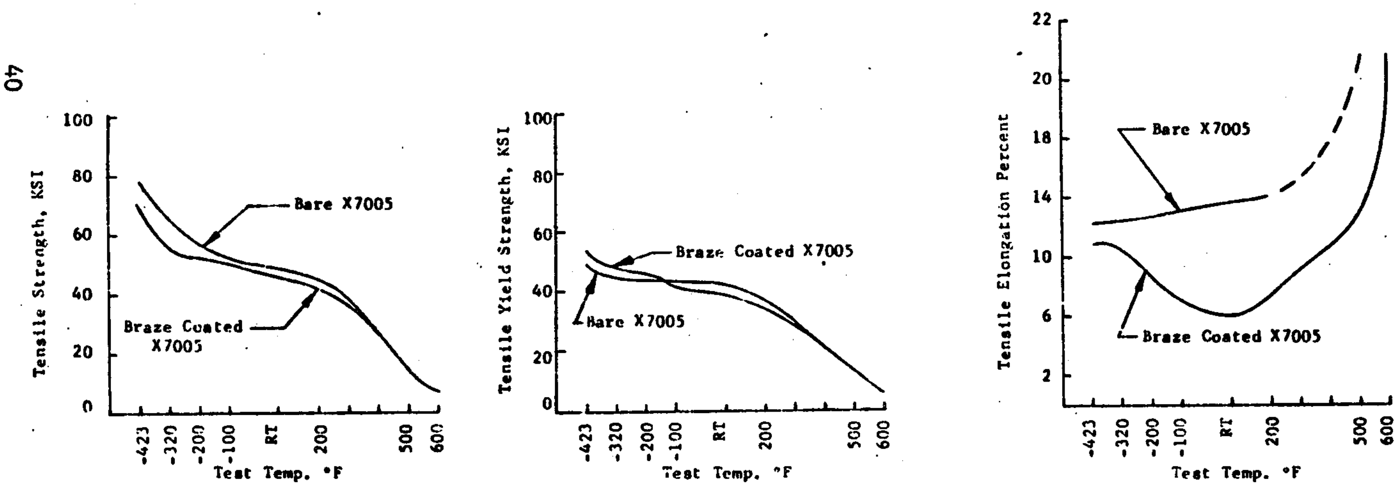
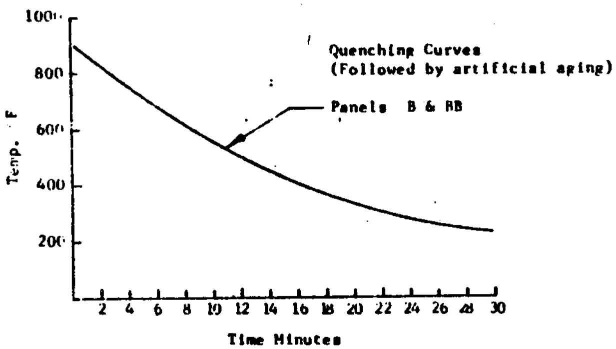


Figure 22 Summary Tensile Data for X7005 Facing Sheets & Extensions from Panels A & AA. Data Points are Based on Averages of Six Tests in Most Cases.

Panels B & BB

X7106, 0.062" Thick. Braze Coated Material had 716 Brazing Alloy



Panels B & BB were Post Braze Heat Treated

ALCOA Tentative Mechanical Properties, X7106-T6, Sheet, Plate, Room Temperature

Typical	
F_{tu}, ksi	61
F_{ty}, ksi	55
Elong. %	13

Minimum	
F_{tu}, ksi	55
F_{ty}, ksi	50
Elong. %	6

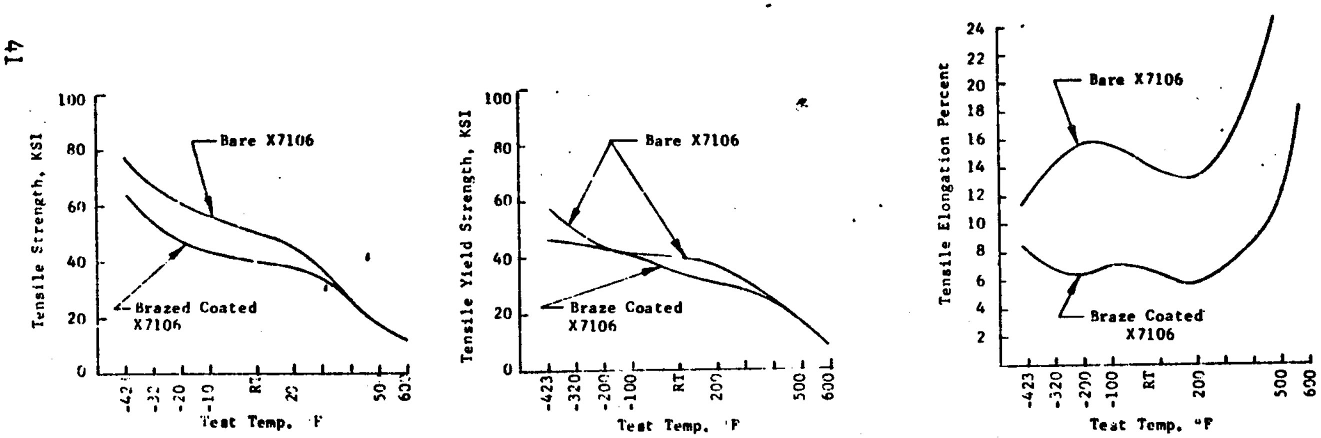
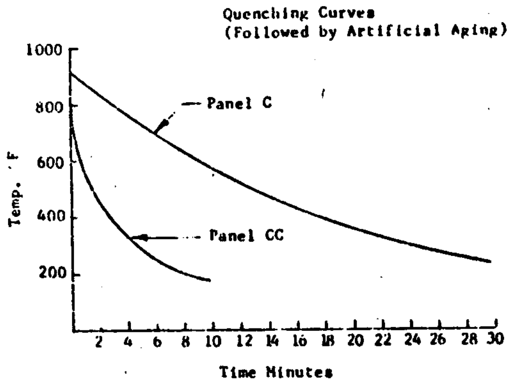


Figure 23 Summary Tensile Data for X7106 Facing Sheet & Extensions from Panels B & BB. Data Points are Based on Averages of Six Tests in Most Cases.

Panels C & CC
7039, 0.062" and 0.090" Thick, Braze Coated Material had 719 Brazing Alloy.



Panels C & CC were Post Braze Heat Treated

KAISER Mechanical Properties,
7039-T6 Sheet, Room Temperature

F_{tu}, ksi	65
F_{ty}, ksi	55
Elong., %	13

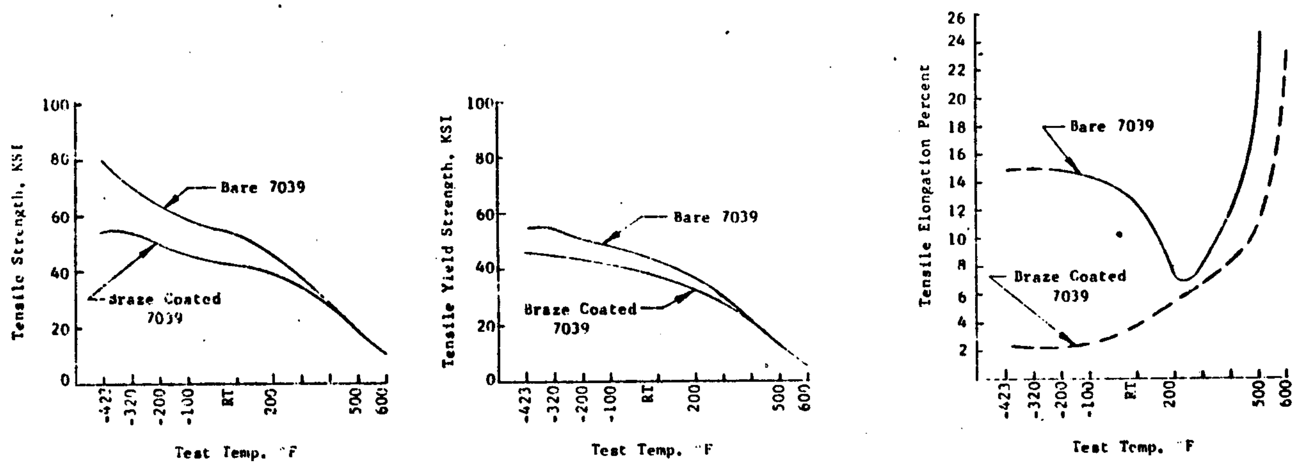
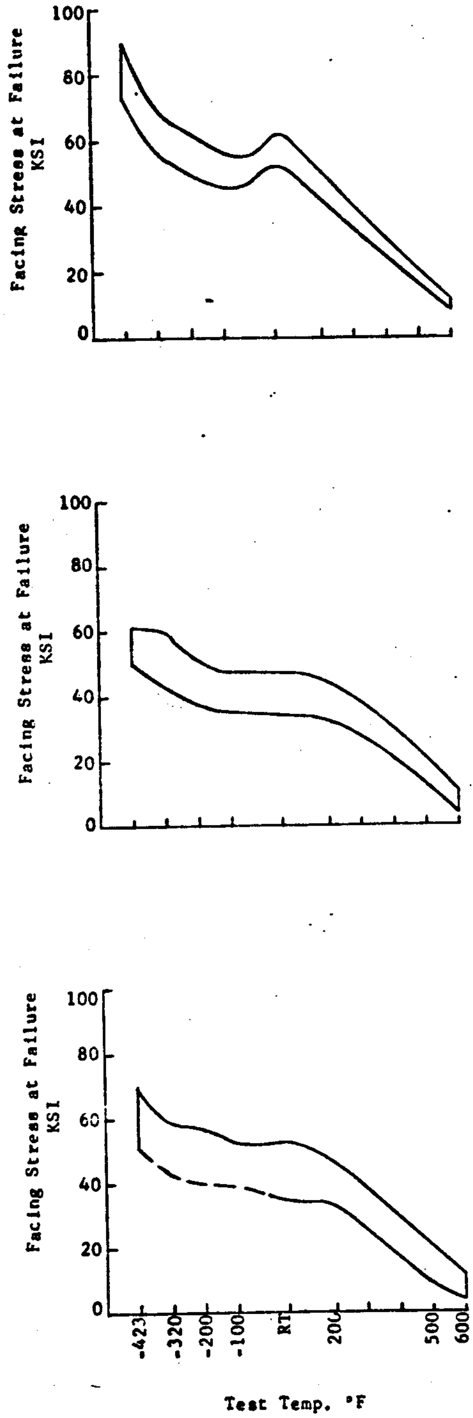


Figure 24 Summary Tensile Data for 7039 Facing Sheet & Extensions from Panels C & CC. Data Points are Based on Averages of Six Tests in Most Cases.

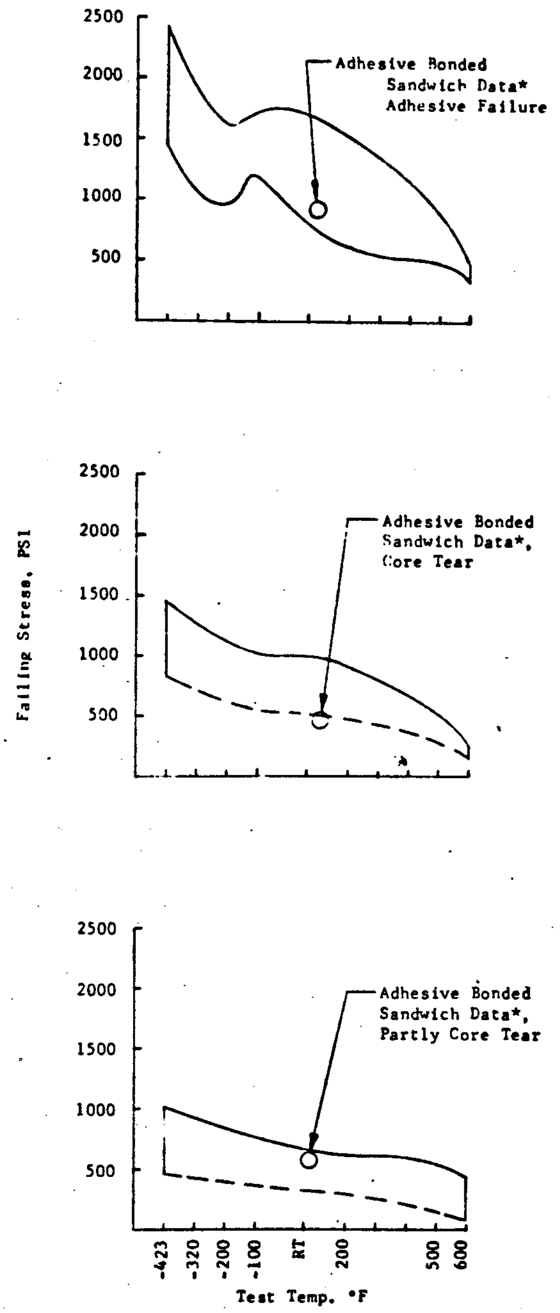


Panels A & AA
Faces: .063" X7005
Core: X7005, 6-80 x½"
Brazing Alloy: 719
Heat Treatment: See preceeding text and figures

Panels B & BB
Faces: .062" X7106
Core: 6951, 6-80 x ½", Square Cell
Brazing Alloy: 716
Heat Treatment: See above

Panels C & CC
Faces: .062" & .090" 7039
Core: 6951, 6-80 x ½" hexagonal cell
Brazing Alloy: 719
Heat Treatment: See above

Figure 25 Summary Data Edgewise Compression Tests. Curves Show the Spread of Six Tests in Most Cases Except for Panels C & CC Where Some Low Values were Deleted Because of Poor Braze Quality.



Panels A & AA

Faces: .063" X7005
Core: X7005, 6-80 x ½"
Hexagonal Cell
Brazing Alloy: 719
Heat Treatment: See preceeding text and figures

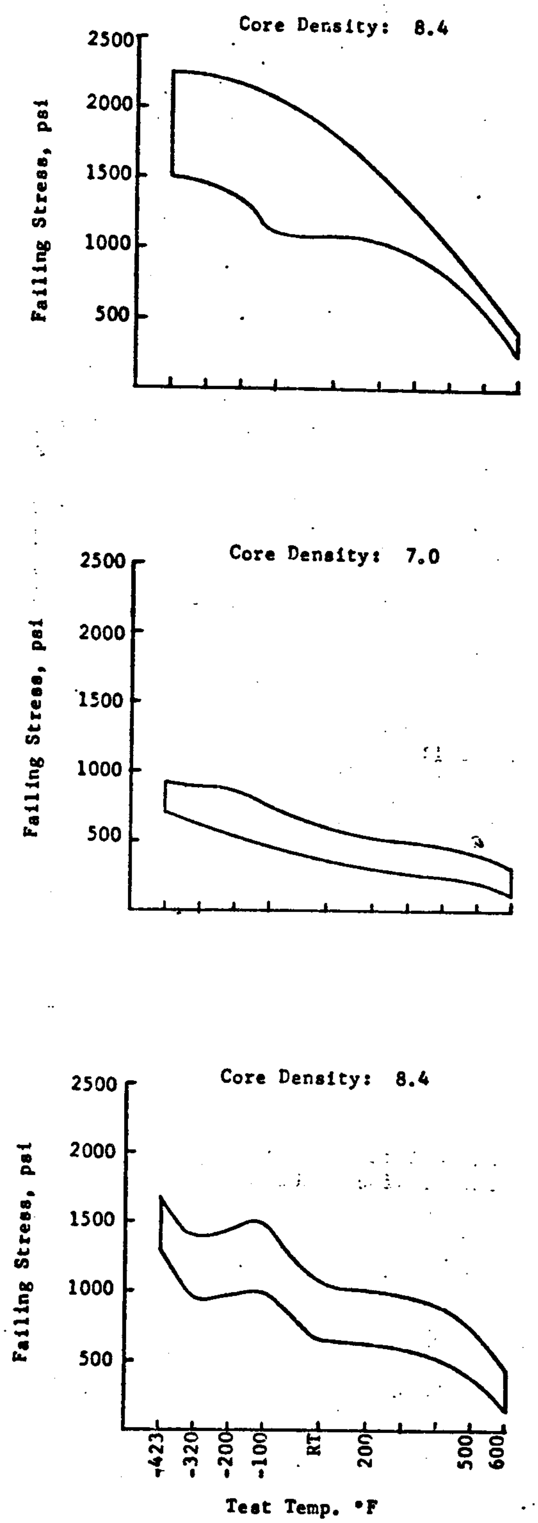
Panels B & BB

Faces: .062" X7106
Core: 6951, 6-80 x ½"
Square Cell
Brazing Alloy: 716
Heat Treatment: See above

Panels C & CC

Faces: .062" & .090" 7039
Core: 6951, 6-80 x ½"
Hexagonal Cell
Brazing Alloy: 719
Heat Treatment: See above

Figure 26 Summary Data on Flatwise Tensile Strength. For X7005, the Data Spread is for Six Specimens Tested at Each Temperature. Because of Specimen Size and Shape the Upper Range of Test Values is Thought to be Most Representative. For Alloys X7106 and 7039 Panels, the Data Spread Represents Only the Upper Range of Test Values. Alloys X7106 and 7039 Were Not as Well Brazed as X7005.



Panels A & AA

Faces: .063" X7005

Core: X7005, 6-80 x ½"
Hexagonal Cell

Brazing Alloy: 719

Heat Treatment: See preceeding text and figures

Panels B & BB

Faces: .062" X7106

Core: 6951, 6-80 x ½"
Square Cell

Brazing Alloy: 716

Heat Treatment: See above

Panels C & CC

Faces: .062" & .090" 7039

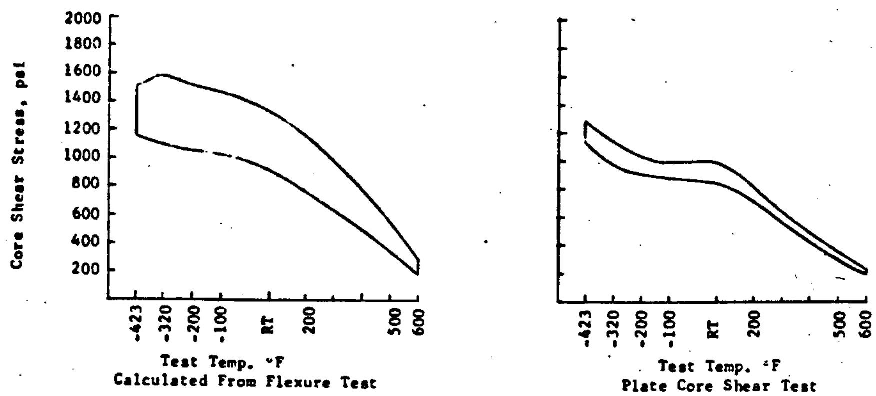
Core: 6951, 6-80 x ½"
Hexagonal Cell

Brazing Alloy: 719

Heat Treatment: See Above

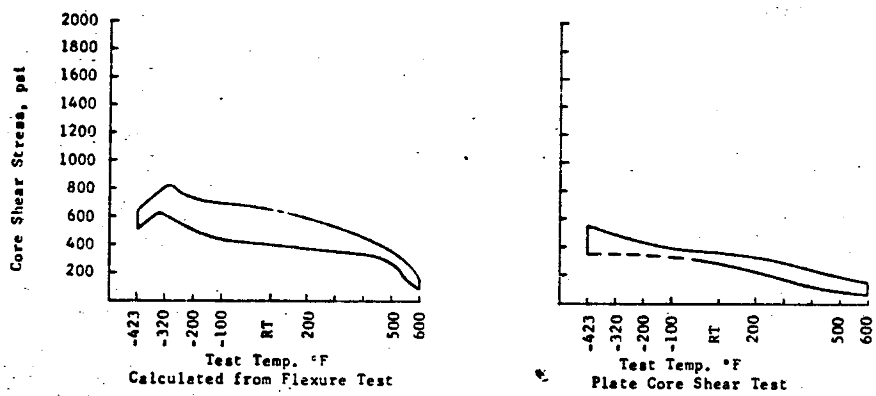
Figure 27 Summary of Data Flatwise Compressive Strength. In Most Cases Data Spread is for Six Specimens Tested at Each Temperature.

Core Density*: 8.4 lb./cu.ft.



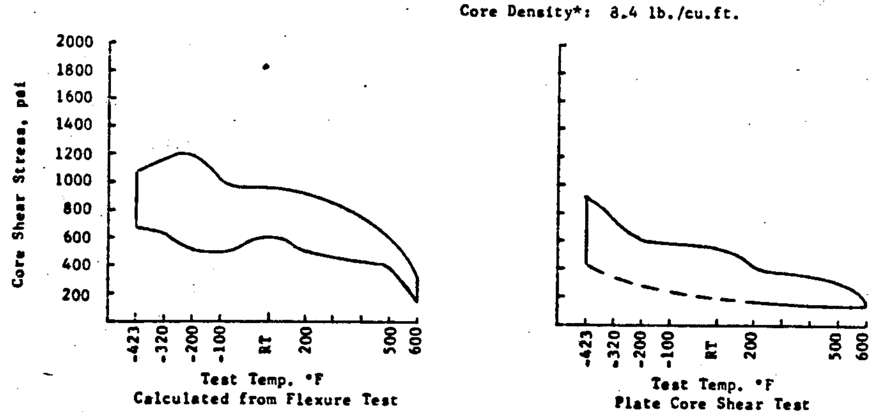
X7005 Core, 6-80 x ½", Hexagonal Cell, Data Spread Includes all Specimens Except Some From Panel A Which Were Clearly Identified as Poorly Brazed by the Inspection Report

Core Density*: 7.0 lb/cu.ft



6951 Core, 6-80 x ½", Square Cell, Data Spread is for Most of the Specimens Tested.

Core Density*: 8.4 lb./cu.ft.



6951 core, 6-60 x ½", Hexagonal Cell, Data spread is for most of the specimens tested.

Figure 2b Summary Data of Core Shear Stress from Both Plate Core Shear Tests and Calculated from Short Beam Flexure Tests.

*Core density was measured.

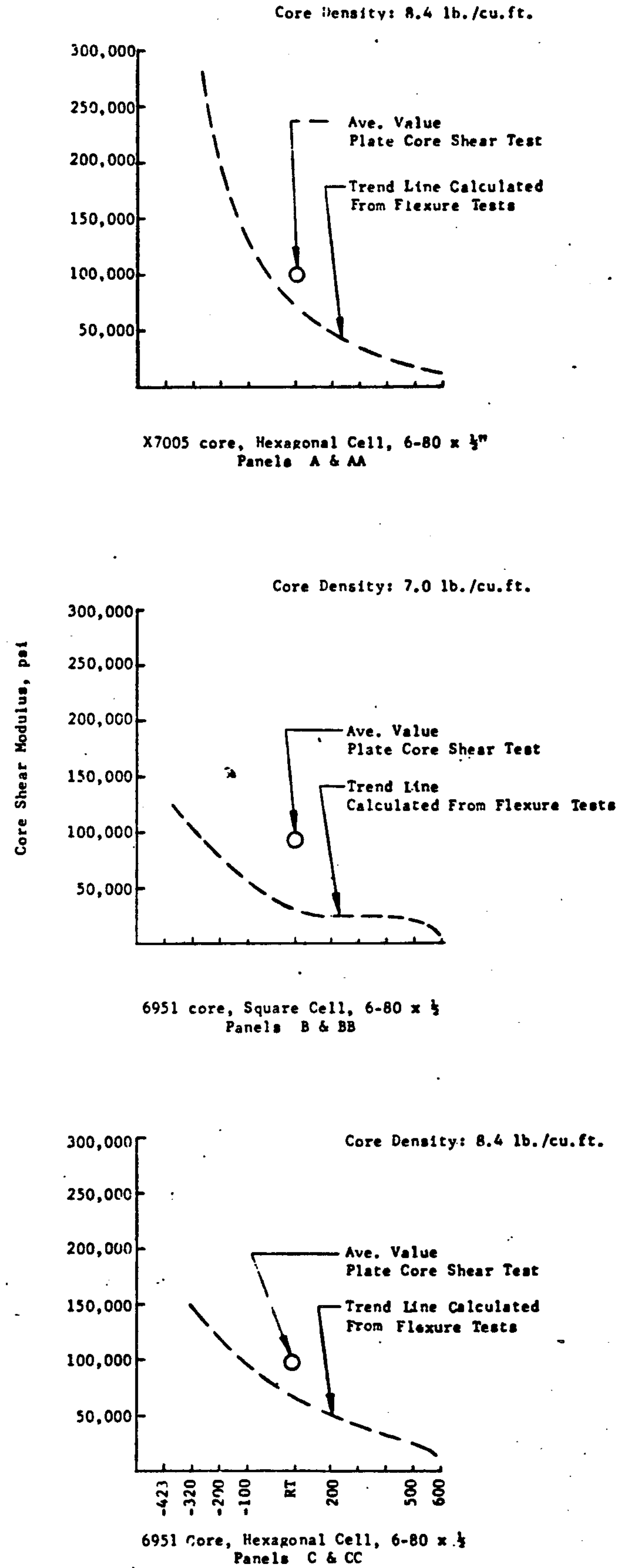


Figure 29 Summary Data on Core Shear Modulus from Both Plate Core Shear Tests and Calculated from Short Beam Flexure Test.

TABLE 3

TENSILE DATA X7005

SANDWICH FACING EXTENSION (NOT COATED WITH BRAZING ALLOY)

PROCESSED WITH SANDWICH PANELS A & AA

	SPECIMEN NUMBER	SPECIMEN THICKNESS INCHES	TEST TEMPERATURE °F	ULTIMATE TENSILE STRENGTH KSI	YIELD STRENGTH 0.2% OFFSET KSI	ELONGATION PERCENT	REMARKS
1.	A	.063	-423	80.4	55.9	10.5	
2.	A	.063		79.6	54.8	13.5	
3.	A	.063		80.9	52.7	13.0	
4.	AA	.063		76.1	43.0	10.0	
5.	AA	.063		70.1	44.8	11.0	
6.	AA	.063		75.7	Not Determined	13.0	
1.	A	.063	-320	62.6	38.9	12.0	
2.	A	.063		63.6	44.3	14.5	
3.	A	.063		62.4	40.9	13.0	
4.	AA	.063		66.4	48.7	10.0	
5.	AA	.063		66.3	47.3	9.5	
1.	A	.063	-200	54.3	43.6	15.0	
2.	A	.063		54.4	44.1	14.5	
3.	A	.063		54.9	Not Determined	12.5	
4.	AA	.064		58.8	46.5	14.0	
5.	AA	.064		60.1	49.2	14.0	
1.	A	.063	-100	53.2	45.2	13.5	
2.	A	.063		51.6	40.7	15.0	
3.	A	.063		52.8	44.0	13.0	
4.	AA	.064		56.3	47.8	9.0	
5.	AA	.064		56.9	47.9	11.0	
1.	A	.063	RT	47.8	38.9	14	
2.	A	.063		48.3	38.9	14	
3.	A	.063		47.5	38.5	14	
4.	AA	.064		50.6	43.8	13	
5.	AA	.064		51.2	43.2	14	
6.	AA	.064		50.4	43.2	13	
1.	A	.063	200	42.4	36.0	14	
2.	A	.063		42.2	35.0	14	
3.	A	.063		42.8	35.6	14	
4.	AA	.063		45.8	40.8	13	
5.	AA	.063		45.0	39.8	14	
6.	AA	.063		45.0	39.9	12	
1.	A	.063	500	12.3	11.0	23.0	
2.	A	.065		11.9	9.8	21.5	
3.	A	.062		13.1	11.0	26.5	
4.	AA	.062		13.5	12.3	24.0	
5.	AA	.063		13.4	12.4	25.5	
1.	A	.063	600	9.4	8.1	32.5	
2.	A	.064		8.8	7.6	35.0	
3.	A	.065		8.7	7.0	33.5	
4.	AA	.065		8.5	7.4	38.5	
5.	AA	.064		9.2	7.0	37.0	

TABLE 4

TENSILE DATA X7005 FACE OF SANDWICH PANELS A & AA

The X7005 faces were coated with brazing alloy 719*

	SPECIMEN NUMBER	SPECIMEN THICKNESS INCHES	TEST TEMPERATURE °F	ULTIMATE TENSILE STRENGTH KSI	YIELD STRENGTH 0.2% OFFSET KSI	ELONGATION PERCENT	REMARKS
1.	A-94	.071	-423	70.2	49.0	12.5	
2.	A-94	.071		70.3	54.2	13.0	
3.	AA-54	.068		71.0	Not Determined	8.0	
4.	AA-54	.068		71.0	Not Determined	8.0	
5.	AA-100	.069		70.4	56.7	7.0	
6.	AA-100	.069		72.1	59.0	9.0	
1.	A-36-1	.066	-320	55.7	44.0	14.5	
2.	A-149	.068		56.0	47.5	11.0	
3.	A-135	.067		54.2	45.0	10.0	
4.	A-148-1	.068		58.3	44.5	14.0	
5.	AA-98	.068		59.3	50.7	8.5	
6.	AA-154	.068		58.8	50.7	9.0	
1.	A-12-1	.069	-200	50.4	47.0	9.0	
2.	A-26-1	.069		50.5	46.0	9.5	
3.	A-68-1	.072		53.7	46.0	10.5	
4.	A-71	.072		53.2	Not Determined	11.0	
5.	AA-56-1	.071		52.8	50.6	2.5	
6.	AA-57-1	.069		52.0	48.8	4.5	
1.	A-149	.070	-100	48.6	43.0	7.5	
2.	A-135	.066		47.3	39.2	7.5	
3.	A-13	.069		48.5	41.6	6.0	
4.	AA-134	.068		52.6	Not Determined	9.0	
5.	AA-99	.069		52.8	Not Det.	Not Det.	Failed Outside Gag
6.	AA-98	.069		51.7	Not Det.	5.0	
1.	A-12-1	.069	RT	49.2	35.0	8.0	
2.	A-109-1	.067		43.5	36.0	6.0	
3.	A-147-1	.067		46.3	35.8	6.0	
4.	AA-55-1	.068		46.1	43.0	3.0	
5.	AA-97-1	.068		46.0	42.8	3.0	
6.	AA-140-1	.068		46.3	43.3	4.0	
1.	A-68	.070	200	41.4	34.2	13.5	
2.	A-146	.070		41.3	31.8	8.0	
3.	A-148	.071		42.5	32.5	9.5	
4.	AA-55	.068		42.8	40.8	5.0	
5.	AA-57	.068		43.0	42.7	4.0	
1.	A-11	.070	500	16.0	15.3	10.0	
2.	A-26	.066		14.2	12.7	14.0	
3.	A-125	.069		15.4	13.9	12.5	
4.	AA-97	.068		15.6	14.3	10.5	
5.	AA-140	.068		13.7	12.8	13.5	
1.	A-2	.063	600	8.9	8.2	22.0	
2.	A-13-2	.067		8.9	7.6	24.5	
3.	A-36	.073		9.2	8.1	24.5	
4.	AA-56	.069		8.9	8.0	25.5	
5.	AA-99	.072		10.1	8.9	19.5	

*Note: Calculations are based on original material thicknesses
True thicknesses (facing plus brazing alloy) are listed above.

TABLE 5

TENSILE DATA X7106

SANDWICH FACING EXTENSION (NOT COATED WITH BRAZING ALLOY)

PROCESSED WITH SANDWICH PANELS B & BB

	SPECIMEN NUMBER	SPECIMEN THICKNESS INCHES	TEST TEMPERATURE °F	ULTIMATE TENSILE STRENGTH KSI	YIELD STRENGTH 0.2% OFFSET KSI	ELONGATION PERCENT	REMARKS
1.	B	.062	-423	70.1	50.5	15.5	
2.	B	.062		78.3	Not Determined	17.0	
3.	B	.062		80.0	55.9	10.5	
4.	BB	.062		81.3	60.2	9.0	
5.	BB	.062		80.0	60.2	8.0	
6.	BB	.062		74.4	59.1	6.0	
1.	B	.062	-320	64.5	44.5	14.5	
2.	B	.062		62.2	41.0	14.0	
3.	BB	.062		68.5	53.2	13.0	
4.	BB	.062		69.8	56.6	15.0	
1.	B	.062	-200	60.0	43.8	19.0	
2.	B	.062		55.2	36.3	13.0	
3.	BB	.062		63.0	Not Determined	12.0	
4.	BB	.062		61.0	45.0	14.5	
1.	B	.062	-100	51.7	42.4	14.0	
2.	B	.062		53.2	37.6	13.0	
3.	BB	.062		57.2	45.0	18.5	
1.	B	.062	RT	52.1	41.8	13	
2.	B	.062		47.7	33.0	16	
3.	B	.062		49.8	36.3	17	
4.	BB	.062		55.1	46.1	10	
5.	BB	.062		54.8	43.2	11	
6.	BB	.062		52.5	39.2	13	
1.	B	.062	200	42.1	34.0	16	
2.	B	.062		43.4	34.9	12.5	
3.	BB	.062		47.7	42.2	11	
4.	BB	.062		47.0	40.5	14	
1.	B	.062	500	15.5	14.6	23.5	
2.	B	.062		16.3	Not Det.	Not Det.	Failed Outside Ga.
3.	BB	.062		17.1	14.2	34.5	
4.	BB	.062		18.1	15.0	24.0	
1.	B	.062	600	9.4	9.1	35.5	
2.	B	.062		11.6	9.2	35.5	
3.	BB	.062		11.8	9.7	35.5	
4.	BB	.062		11.4	9.2	34.5	

TABLE 6

TENSILE DATA X7106 FACE OF SANDWICH PANELS B & BB

The X7106 faces were coated with brazing alloy 716*

	SPECIMEN NUMBER	SPECIMEN THICKNESS INCHES	TEST TEMPERATURE °F	ULTIMATE TENSILE STRENGTH KSI	YIELD STRENGTH 0.2% OFFSET KSI	ELONGATION PERCENT	REMARKS
1.	B-40	.073	-423	72.5	46.7	15.0	
2.	B-40	.069		69.3	45.2	15.0	
3.	B-55	.072		72.3	50.6	13.5	
4.	B-88	.072		69.7	49.5	9.0	
5.	BB-100	.069		50.7	46.3	2.0	
6.	BB-102	.070		48.9	43.0	2.5	
1.	B-59-1	.072	-320	66.8	48.8	10.0	
2.	B-61	.070		63.3	44.6	12.5	
3.	B-86-2	.075		62.9	46.8	14.0	
4.	BB-2-1	.068		37.2	Not Determined	1.8	
5.	BB-106-1	.068		44.9	43.4	3.5	
6.	BB-106-2	.066		46.3	Not Determined	4.5	
1.	B-58	.071	-200	54.2	Not Determined	16.0	
2.	B-86-1	.067		52.7	45.7	13.5	
3.	B-84-1	.068		50.8	44.2	10.5	
4.	BB-103-1	.068		43.5	38.8	2.0	
5.	BB-105-1	.067		40.8	Not Determined	2.5	
6.	BB-125	.068		38.8	Not Determined	1.5	
1.	B-57-1	.072	-100	56.5	53.0	12.5	
2.	B-63-1	.073		53.2	40.5	13.0	
3.	B-87-1	.074		53.0	41.2	10.5	
4.	BB-4	.069		30.5	Not Determined	3.5	
5.	BB-105	.070		37.0	Not Determined	2.5	
1.	B-58	.068	RT	46.4	36.3	12.0	
2.	B-59	.071		4[illegible].2	32.5	10.5	
3.	B-85	.069		39.8	32.8	8.5	
4.	BB-3	.069		29.2	28.9	0.25	
5.	BB-103	.073		36.0	Not Determined	3.5	
6.	BB-104	.068		39.1	32.8	2.5	
1.	B-57	.072	200	48.7	42.0	10.5	
2.	B-84	.071		44.5	37.3	Not Det.	Failed Outside Gage
3.	B-87	.068		42.7	35.7	9.5	
4.	BB-85	.068		35.8	31.8	1.0	
5.	BB-85	.073		31.2	27.7	0.5	
6.	BB-101	.074		34.6	30.0	3.0	
1.	B-54	.069	500	17.3	14.1	18.5	
2.	B-63	.070		17.2	15.0	21.0	
3.	B-86	.073		16.2	15.3	13.5	
4.	BB-1	.070		16.4	14.8	8.0	
5.	BB-58-1	.067		17.6	15.2	6.5	
6.	BB-58-2	.072		18.1	15.2	7.5	
1.	B-53	.070	600	10.9	8.4	33.5	
2.	B-54	.070		11.5	9.2	37.0	
3.	BB-2	.067		10.6	10.1	17.0	
4.	BB-125	.068		11.1	8.4	13.0	

*Note: Calculations are based on original material thicknesses
True thicknesses (facing plus brazing alloy) are listed above.

TABLE 7

TENSILE DATA 7039

SANDWICH FACING EXTENSION (NOT COATED WITH BRAZING ALLOY)

PROCESSED WITH SANDWICH PANELS C & CC

	SPECIMEN NUMBER	SPECIMEN THICKNESS INCHES	TEST TEMPERATURE °F	ULTIMATE TENSILE STRENGTH KSI	YIELD STRENGTH 0.2% OFFSET KSI	ELONGATION PERCENT	REMARKS
1.	C	.062	-423	68.0	Not Determined	13.0	
2.	C	.062		81.3	39.8	28.5	
3.	C	.062		70.1	40.9	8.0	
4.	CC	.089		89.0	62.2	15.5	
5.	CC	.089		87.2	67.4	9.0	
6.	CC	.089		91.1	59.9	14.5	
1.	C	.062	-320	60.4	Not Determined	11.5	
2.	C	.061		65.2	41.0	16.0	
3.	CC	.089		77.6	70.0	12.5	
4.	CC	.089		67.2	62.1	9.0	
1.	C	.062	-200	53.3	32.1	17.0	
2.	C	.061		54.4	32.5	15.0	
3.	C	.061		55.3	33.8	Not Det.	Failed Outside G
4.	CC	.089		81.8	62.8	15.0	
5.	CC	.089		75.2	Not Determined	12.5	
1.	C	.063	-100	48.9	31.2	13.5	
2.	C	.063		51.7	36.6	15.0	
3.	CC	.090		64.4	55.0	16.0	
4.	CC	.090		63.2	55.5	15.0	
1.	C	.062	RT	46.4	32.0	12.0	
2.	C	.062		47.5	34.0	11.5	
3.	C	.062		48.5	34.9	15.0	
4.	CC	.089		62.2	54.9	12.0	
5.	CC	.089		59.7	51.3	13.5	
6.	CC	.089		61.3	53.7	13.5	
1.	C	.062	200	41.0	32.8	5.0	Gage Line Failur
2.	C	.062		39.5	30.4	14.0	
3.	C	.062		35.0	31.1	3.0	
4.	CC	.088		54.5	45.3	5.0	
5.	CC	.088		55.6	47.3	5.0	
6.	CC	.088		56.4	47.9	10.0	Gage Line Failur
1.	C	.062	500	18.5	17.7	25.5	
2.	C	.062		15.3	13.9	25.0	
3.	C	.062		16.7	16.0	31.5	
4.	C	.062		18.3	16.1	23.5	
5.	CC	.089		20.4	17.7	20.5	
6.	CC	.089		20.5	17.8	22.5	
7.	CC	.089		18.7	16.6	20.5	
1.	C	.062	600	10.8	6.4	44.0	
2.	C	.062		11.1	7.8	46.0	
3.	CC	.089		10.5	8.2	42.5	

TABLE 8

TENSILE DATA 7039 FACES OF SANDWICH PANELS C & CC

The 7039 faces were coated with brazing alloy 719*

	SPECIMEN NUMBER	SPECIMEN THICKNESS INCHES	TEST TEMPERATURE °F	ULTIMATE TENSILE STRENGTH KSI	YIELD STRENGTH 0.2% OFFSET KSI	ELONGATION PERCENT	REMARKS
1.	C-2	.069	-423	55.0	43.0	3.0	
2.	C-5	.067		49.5	45.2	0.5	
3.	C-5	.066		50.8	45.1	1.0	
4.	CC-2	.095		62.0	53.8	1.0	
5.	CC-16	.095		48.8	None	0.0	
6.	CC-38	.095		51.9	None	0.0	
1.	C-3-1	.067	-320	58.0	41.2	10.0	
2.	C-167-1	.062		53.6	32.2	15.0	
3.	CC-17-1	.095		54.2	49.1	Not Det.	Failed Outside G.
1.	C-75	.069	-200	40.3	Not Det.	3.0	
2.	C-169	.062		46.4	44.5	5.0	
3.	CC-3	.097		47.6	Not Det.	Not Det.	Failed Outside G
4.	CC-41	.097		Not Det.	Not Det.	Not Det.	Failed Outside G
1.	C-3	.069	-100	50.5	Not Det.	3.0	
2.	C-60	.069		45.8	40.0	3.0	
3.	CC-3	.095		49.5	Not Det.	3.0	
4.	CC-55	.096		53.0	Not Det.	1.0	
1.	C-4	.067	RT	46.0	34.2	6.0	
2.	C-6	.069		38.0	36.4	3.0	
3.	C-167	.068		34.7	31.3	4.0	
4.	CC-1	.097		47.7	45.3	3.0	
5.	CC-17	.096		41.8	41.3	2.0	
6.	CC-83	.098		46.2	43.7	0.5	
1.	C-4	.070	200	40.7	32.5	11.0	
2.	C-6	.067		37.2	29.8	3.0	
3.	C-166	.071		39.2	34.2	15.0	
4.	CC-2	.095		45.6	Not Det.	3.0	
5.	CC-39	.095		43.5	39.8	Not Det.	Failed Outside G
6.	CC-83	.096		46.8	Not Det.	5.0	
1.	C-2-1	.066	500	16.4	15.0	10.5	
2.	C-75	.066		18.0	14.3	5.5	
3.	C-33-2	.068		18.4	16.0	10.0	
4.	CC-38	.095		14.8	12.7	9.0	
5.	CC-39	.095		17.8	15.5	7.5	
6.	CC-95-2	.095		18.6	15.5	9.0	
1.	C-60	.068	600	11.3	7.9	20.0	
2.	C-165	.067		9.8	6.7	29.0	
3.	CC-1	.096		11.0	7.2	25.0	
4.	CC-16	.096		9.3	Not Det.	39.0	

*Note: Calculations are based on original material thicknesses
True thicknesses (facing plus brazing alloy) are listed above.

TABLE 9

EDGEWISE COMPRESSION TESTS - SANDWICH SPECIMENS A & AA

NOMINAL SPECIMEN SIZE: 0.6" x 2" x 3"

Faces: X7005

Core: X7005 type 6-80 x ½", hexagonal cell

Brazing Alloy: 719

	SPECIMEN NUMBER	TEST TEMPERATURE °F	FACING STRESS AT FAILURE psi	REMARKS
1.	A143	-423	84,900	Face Separation
2.	AA42		89,400	Shear Crimping
3.	AA46		89,000	Face Separation
4.	AA50		Fixture broke did not re-run	
5.	AA85		83,200	Shear Crimping
6.	AA94		75,800	Shear Crimping
1.	A107	-320	66,000	Face Wrinkling Outward
2.	AA5		62,200	Face Wrinkling Outward
3.	AA13		60,700	Not Available
4.	AA132		61,100	Shear Crimping
5.	AA131		64,300	Face Wrinkling Outward
6.	AA161		57,500	Face Wrinkling Outward
1.	A99	-200	61,200	Face Wrinkling Outward
2.	AA52		62,800	Face Wrinkling Outward
3.	AA88		64,400	Face Wrinkling Outward
4.	AA89		60,000	Face Wrinkling Outward
5.	AA137		52,600	Face Wrinkling Outward
6.	AA139		58,400	Face Wrinkling Outward
1.	A122	-100	48,100	Face Wrinkling Outward
2.	AA11		53,700	Shear Crimping
3.	AA12		50,400	Face Wrinkling Outward
4.	AA133		52,300	Face Wrinkling Outward
5.	AA134		46,000	Face Wrinkling Outward
6.	AA138		52,100	Face Wrinkling Outward
1.	A130	RT	61,000	Shear Crimping
2.	AA141		59,000	Face Wrinkling Outward
3.	AA8		58,000	Shear Crimping
4.	AA34		59,000	Not Available
5.	AA36		56,000	Not Available
6.	AA38		56,000	Face Wrinkling Outward
1.	A133	+200	44,000	Shear Crimping
2.	AA1		43,500	Shear Crimping
3.	AA28		44,500	Shear Crimping
4.	AA30		51,000	Shear Crimping
5.	AA44		52,000	Shear Crimping
6.	AA84		43,500	Shear Crimping
1.	AA48	+500	18,900	Shear Crimping
2.	AA86		17,500	Shear Crimping
3.	AA87		15,900	Shear Crimping
4.	AA93		16,000	Shear Crimping
5.	AA95		18,200	Shear Crimping
6.	AA96		16,800	Shear Crimping
1.	AA2	+600	8,800	Shear Crimping
2.	AA32		9,900	Shear Crimping
3.	AA9·		9,900	Face Wrinkling Outward
4.	AA91		8,700	Shear Crimping
5.	AA92		10,200	Shear Crimping
6.	Not Available			

TABLE 10

EDGEWISE COMPRESSION TESTS - SANDWICH SPECIMENS B & BB

NOMINAL SPECIMEN SIZE: 0.6" x 2" x 3"

Faces: X7106

Core: 6951 type 6-80 x ½", square cell

Brazing Alloy: 716

	SPECIMEN NUMBER	TEST TEMPERATURE °F	FACING STRESS AT FAILURE psi	REMARKS
1.	B15	-423	60,800	Shear Crimping
2.	B18		59,400	Shear Crimping
3.	B21		51,900	Shear Crimping
4.	BB23		63,800	Not Available
5.	BB27		49,900	Not Available
6.	BB67		51,300	Facing Separation
1.	B17	-320	48,400	Face Separation
2.	B137		60,300	Face Separation
3.	B139		53,700	Face Separation
4.	BB24		53,200	Face Wrinkling Outward
5.	BB47		42,900	Face Wrinkling Outward
6.	Not Available			
1.	B117	-200	44,800	Face Separation
2.	B119		45,900	Face Wrinkling Outward
3.	B123		47,000	Face Separation
4.	BB20		34,600	Face Separation
5.	BB22		37,400	Face Wrinkling Outward
6.	Not Available			
1.	B23	-100	47,000	Shear Crimping
2.	B24		44,400	Shear Crimping
3.	B140		43,800	Face Wrinkling Outward
4.	BB21		34,400	Face Separation
5.	BB28		37,400	Face Wrinkling Outward
6.	Not Available			
1.	B14	RT	41,500	Shear Crimping
2.	B19		49,000	Shear Crimping
3.	B22		49,000	Shear Crimping
4.	B141		21,500	Shear Crimping
5.	BB17		28,500	Face Separation
6.	BB25		43,000	Shear Crimping
1.	B20	+200	35,900	Shear Crimping
2.	B25		41,000	Shear Crimping
3.	B120		45,500	Shear Crimping
4.	B138		36,500	Shear Crimping
5.	BB19		36,200	Face Separation
6.	Not Available			
1.	B26	+500	18,300	Shear Crimping
2.	B118		19,500	Shear Crimping
3.	B122		17,000	Shear Crimping
4.	BB18		12,900	Facing Separation
5.	BB56		20,300	Shear Crimping
6.	Not Available			
1.	B16	+600	9,400	Shear Crimping
2.	B116		5,500	Face Wrinkling Inward
3.	B121		10,100	Shear Crimping
4.	BB57		10,900	Shear Crimping
5.	BB68		9,600	Shear Crimping
6.	Not Available			

TABLE 11

EDGEWISE COMPRESSION TESTS - SANDWICH SPECIMENS C & CC

NOMINAL SPECIMEN SIZE: 0.6" x 2" x 3"

Faces: 7039

Core: 6951 type 6-80 x ⅛", hexagonal cell

Brazing Alloy: 719

	SPECIMEN	TEST TEMPERATURE °F	FACING STRESS AT FAILURE psi	FAILURE MODE
1.	C47	-423	55,400	Shear Crimping
2.	C61		52,800	Shear Crimping
3.	C152		53,700	Face Separation
4.	CC56		42,800	Face Separation
5.	CC60		64,600	Not Available
6.	CC61		68,200	Not Available
1.	C49	-320	36,000	Face Separation
2.	C63		21,000	Face Separation
3.	C100		47,200	Face Separation
4.	C135		39,500	Face Separation
5.	C147		52,400	Face Separation
6.	CC59		56,500	Face Separation
1.	C55	-200	35,800	Face Separation
2.	C73		42,300	Face Separation
3.	C106		50,800	Face Separation
4.	C140		40,300	Face Separation
5.	C156		28,800	Face Separation
6.	CC54		57,700	Face Separation
1.	C48	-100	32,700	Face Separation
2.	C53		19,700	Face Separation
3.	C56		39,600	Face Separation
4.	C65		17,200	Face Separation
5.	C137		25,200	Face Separation
6.	CC64		48,300	Face Separation
1.	C57	RT	30,500	Shear Crimping
2.	C58		41,200	Shear Crimping
3.	C71		39,900	Face Separation
4.	C96		27,700	Face Separation
5.	CC53		57,900	Face Separation
6.	CC58		56,500	Face Separation
1.	C64	+200	17,900	Face Separation
2.	C68		6,700	Face Separation
3.	C72		40,800	Shear Crimping
4.	C104		36,700	Face Separation
5.	C162		43,600	Face Separation
6.	CC63		45,600	Shear Crimping
1.	C52	+500	7,600	Face Separation
2.	C54		6,300	Shear Crimping
3.	C62		18,500	Shear Crimping
4.	C97		10,200	Shear Crimping
5.	C98		7,700	Shear Crimping
6.	CC62		20,200	Shear Crimping
1.	C105	+600	8,300	Shear Crimping
2.	C107		11,500	Shear Crimping
3.	C132		3,800	Shear Crimping
4.	C154		8,500	Shear Crimping
5.	C158		9,300	Shear Crimping
6.	CC57		8,400	Shear Crimping

TABLE 12

FLATWISE TENSILE TESTS - SANDWICH SPECIMENS A & AA

Faces: X7005

Core: X7005 type 6-80 x ½", hexagonal cell

Brazing Alloy: 719

	SPECIMEN NUMBER	SPECIMEN SIZE	TEST TEMPERATURE °F	FAILING STRESS psi	FAILURE MODE
1.	A32	2" x 2"	-423	2,460	Core Tear
2.	A37			1,970	Braze
3.	A38			2,330	Braze
4.	AA29			1,820	Braze and Core Root
5.	AA31			1,820	Braze and Core Root
6.	AA75			1,480	Braze and Core Root
1.	A17	1" x 2"	-320	1,820	Adhesive
2.	A118			1,540	Braze
3.	AA41			1,520	50% Core Tear
4.	AA120			1,080	Braze
5.	AA124			960	Braze
6.	Not Available				
1.	A121	1" x 2"	-200	1,600	Braze
2.	A128			1,380	Adhesive
3.	AA19			1,580	50% Core Tear
4.	AA33			1,240	Braze
5.	AA118			1,070	Braze
6.	Not Available				
1.	A81	1" x 2"	-100	1,710	Core Tear
2.	A119			1,730	Braze
3.	A143			1,730	50% Core Tear
4.	AA45			1,670	Core Tear
5.	AA121			1,230	Adhesive
6.	A40			1,620	50% Core Tear
1.	A39	1" x 2"	Room Temperature	1,730	Adhesive
2.	AA25			1,370	Braze
3.	A97			1,070	Braze
4.	A65			1,080	Braze
5.	AA72			1,250	Core Tear
6.	AA123			720	Braze
1.	AA22	1" x 2"	200	1,080	Core Tear
2.	A104	1" x 2"		600	Braze
3.	A33	2" x 2"		1,500	Adhesive
4.	A79	1" x 2"		1,530	Core Tear
5.	AA14	1" x 2"		1,220	Core Tear
6.	AA47	1" x 2"		1,370	Core Tear
1.	A139	2" x 2"	500	880	Core Tear
2.	A111	2" x 2"		698	Adhesive
3.	AA37	2" x 2"		710	Adhesive
4.	AA83	1" x 2"		726	Core Tear
5.	AA125	1" x 2"		500	Braze
6.	A132	1" x 2"		720	Core Tear
1.	A82	1" x 2"	600	415	Core Tear
2.	A127			411	Core Tear
3.	A142			450	Core Tear
4.	AA82			349	Core Tear
5.	AA35			420	Core Tear
6.	AA43			363	Core Tear

TABLE 13

FLATWISE TENSILE TESTS - SANDWICH SPECIMENS B & BB

Faces: X7106

Core: 6951, type 6-80 x ½", modified square cell

Brazing Alloy: 716

	SPECIMEN NUMBER	SPECIMEN SIZE	TEST TEMPERATURE °F	FAILING STRESS psi	FAILURE MODE
1.	B35	2" x 2"	-423	930	Braze
2.	B100			1,370	Braze
3.	B107			1,220	Braze
4.	BB32			1,330	Braze & Core Tear
5.	BB76			1,050	Braze
6.	BB90			323	Braze
1.	BB59	2" x 2"	-320	450	Braze
2.	BB79			132	"
3.	BB91			126	"
4.	B68			447	"
5.	B69			556	"
6.	Not Available				
1.	B22	2" x 2"	-200	351	Braze
2.	B70			625	"
3.	BB29			546	"
4.	BB39 Hex			0 Failed Prior to Test	"
5.	BB89			129	"
6.	Not Available				
1.	B93-1	2" x 2"	-100	1,130	Adhesive
2.	BB31			977	Braze
3.	BB33			519	Core Tear
4.	BB92			496	Braze
5.	B105			868	Core Tear
6.	B114			722	Braze
1.	B67	1" x 2"	Room Temperature	230	Braze
2.	B38	2" x 2"		680	Braze
3.	B49			510	Braze
4.	B99			1,070	Braze
5.	B102			745	Braze
6.	B103			820	Core Tear
1.	B24	1" x 2"	200	880	Braze
2.	BB93	1" x 2"		330	Braze
3.	BB108	1" x 2"		80	Braze
4.	B32	2" x 2"		870	Core Tear
5.	B93-2	2" x 2"		180	Braze
6.	BB81	2" x 2"		350	Braze
1.	BB37 Hex	1" x 2"	500	370	Braze
2.	BB78			125	Braze
3.	B96			610	Core Tear
4.	B113			540	Core Tear
5.	B135			380	Core Tear
6.	BB98	2" x 2"		187	Braze
1.	B37	1" x 2"	600	260	Core Tear
2.	BB34	2" x 2"		210	Core Tear
3.	BB66			201	Braze
4.	B28			246	Core Tear
5.	B29			235	Core Tear
6.	Not Available				

TABLE 14

FLATWISE TENSILE TESTS - SANDWICH SPECIMENS C & CC

Faces: 7039

Core: 6951 type 6-80 x ⅓", hexagonal cell

Brazing Alloy: 719

	SPECIMEN NUMBER	SPECIMEN SIZE	TEST TEMPERATURE °F	FAILING STRESS psi	FAILURE MODE
1.	C34	2" x 2"	-423	861	Braze
2.	C128			845	Braze
3.	C151			1030	Braze
4.	CC6			530	Braze
5.	CC13			766	Braze
6.	CC92			640	Braze
1.	C24	2" x 2"	-320	197a	Braze
2.	C32			0 Failed Prior to Test	"
3.	C139			54	"
4.	CC10			292	"
5.	CC8			164	"
6.	Not Available				
1.	C119	2" x 2"	-200	280	Braze
2.	C131			395	"
3.	C161			315	"
4.	CC19			231	"
5.	CC75			290	"
6.	CC107			83	"
1.	C35	2" x 2"	-100	52	Braze
2.	C145			55	"
3.	C153			174	"
4.	CC18			240	"
5.	CC26			485	"
6.	CC70			485	"
1.	C148	1" x 2"	Room Temperature	450	Braze
2.	C42	2" x 2"		128	"
3.	CC81			425	"
4.	CC23			515	"
5.	CC80			400	"
6.	CC168			70	"
1.	C28	2" x 2"	200	207	Braze
2.	C31			620	"
3.	C129			715	"
4.	C37			120	"
5.	C45			345	"
6.	C134			340	"
1.	C120	2" x 2"	500	250	Braze
2.	CC67			705	"
3.	CC72			460	"
4.	C30			500	"
5.	CC74			560	"
1.	CC66	2" x 2"	600	437	Braze
2.	CC73			390	"
3.	C141			140	"
4.	Not Available				
5.	" "				
6.	" "				

TABLE 15

FLATWISE COMPRESSION TESTS - SANDWICH SPECIMENS A & AA

Faces: X7005

Core: X7005 type 6-80 x ½", hexagonal cell

Brazing Alloy: 719

	SPECIMEN NUMBER	SPECIMEN SIZE	TEST TEMPERATURE °F	FAILING STRESS psi	REMARKS
1.	A91	2" x 2"	-423	2,225	
2.	A116			2,102	
3.	A126			2,401	
4.	AA20			1,975	
5.	AA21			2,002	
6.	AA126			1,218	
1.	A19	2" x 2"	-320	1,928	
2.	A21			1,620	
3.	A89			1,680	
4.	A101			1,880	
5.	AA15			1,560	
6.	AA18			1,800	
7.	AA119			1,520	
1.	A20	2" x 2"	-200	1,640	
2.	A137			2,350	
3.	A-138			2,030	
4.	AA17			1,370	
5.	AA73			1,840	
6.	AA79			1,850	
1.	A78	2" x 2"	-100	1,801	
2.	A125			1,799	
3.	AA39			1,074	
4.	AA115			1,454	
5.	AA116			1,534	
6.	Not Available				
1.	A18	2" x 2"	Room Temperature	1,170	
2.	A64			1,420	
3.	A83			1,220	
4.	AA71			1,230	
5.	AA76			1,350	
6.	AA77			1,650	
1.	A22	2" x 2"	200	1,270	
2.	A84			1,120	
3.	A96			1,360	
4.	AA49			1,545	
5.	AA51			1,550	
6.	AA74			1,184	
1.	A10	2" x 2"	500	590	
2.	A106			590	
3.	A124			500	
4.	AA16			590	
5.	AA27			720	
6.	AA122			610	
1.	AA26	2" x 2"	600	370	
2.	AA78			260	
3.	AA80			320	
4.	A95			310	
5.	A98			350	
6.	A113			360	

TABLE 16

FLATWISE COMPRESSION TESTS - SANDWICH SPECIMENS B & BB

Faces: X7106

Core: 6951 type 6-80 x ½", square cell

Brazing Alloy: 716

	SPECIMEN NUMBER	SPECIMEN SIZE	TEST TEMPERATURE °F	FAILING STRESS psi	REMARKS
1.	B97	2" x 2"	-423	837	
2.	B109			614	
3.	B115			703	
4.	BB74			801	
5.	BB77			824	
6.	BB86			881	
1.	B27	2" x 2"	-320	350	
2.	B34			430	
3.	B76			650	
4.	BB35			1225	Hex Cell
5.	BB66			840	
6.	BB80			820	
1.	B91	2" x 2"	-200	675	
2.	B104			490	
3.	B108			490	
4.	BB48			790	
5.	BB55			720	
6.	BB75			760	
1.	B33	2" x 2"	-100	460	
2.	B95			450	
3.	B98			590	
4.	BB36			1535	Hex Cell
5.	BB44			670	
6.	Not Available				
1.	B31	2" x 2"	Room Temperature	395	
2.	B110			438	
3.	B111			435	
4.	BB40			1216	Hex Cell
5.	BB73			611	
6.	Not Available				
1.	B39	2" x 2"	200	426	
2.	B71			282	
3.	B101			507	
4.	B109			389	
5.	B111			326	
6.	Not Available				
1.	B30	2" x 2"	500	240	
2.	B94			320	
3.	BB30			280	
4.	BB82			340	
5.	BB87			350	
6.	Not Available				
1.	B75	2" x 2"	600	190	
2.	B106			140	
3.	BB38			310	
4.	BB69			190	
5.	BB88			120	
6.	Not Available				

TABLE 17

FLATWISE COMPRESSION TESTS - SANDWICH SPECIMENS C & CC

Faces: 7039

Core: 6951 type 6-80 x ½", hexagonal cell

Brazing Alloy: 719

	SPECIMEN NUMBER	SPECIMEN SIZE	TEST TEMPERATURE °F	FAILING STRESS psi	REMARKS
1.	C20	2" x 2"	-432	1,705	
2.	C46			1,578	
3.	C117			1,372	
4.	CC9			1,578	
5.	CC11			1,367	
6.	CC24			1,300	
1.	C22	2" x 2"	-320	1,400	
2.	C40			1,250	
3.	C157			995	
4.	CC68			890	
5.	CC93			1,040	
1.	C3	2" x 2"	-200	1,430	
2.	C121			1,170	
3.	C124			1,200	
4.	CC15			1,040	
5.	CC21			1,290	
6.	CC82			1,120	
1.	C21	2" x 2"	-100	1,530	
2.	C43			1,060	
3.	C155			1,350	
4.	CC14			1,020	
5.	CC20			1,210	
6.	CC106			1,090	
1.	C27	2" x 2"	Room Temperature	620	
2.	C29			890	
3.	C44			1,070	
4.	C138			940	
5.	CC25			850	
6.	CC94			740	
1.	C26	2" x 2"	200	830	
2.	C23			1,180	
3.	C122			900	
4.	CC7			1,010	
5.	CC27			790	
6.	CC71			710	
1.	C41	2" x 2"	500	460	
2.	C120			370	
3.	C127			360	
4.	CC22			580	
5.	CC69			690	
6.	CC78			400	
1.	C118	2" x 2"	600	210	
2.	C123			270	
3.	C163			310	
4.	CC65			290	
5.	CC77			380	

TABLF 18

FLEXURE TESTS*- SANDWICH SPECIMENS A & AA

Faces: X7005

Core: X7005 type 6-80 x ¼", hexagonal cell

Brazing Alloy: 719

	SPECIMEN NUMBER	TEST TEMP. °F	CORE DIRECTION	FACING STRESS AT CORE OR BRAZE FAILURE PSI	CORE SHEAR STRESS PSI	CORE SHEAR MODULUS PSI
1.	A 34	-423		23,300	1440	
2.	AA 60			23,500	1460	
3.	AA 61			23,300	1440	Not Determined
4.	AA 104			19,400	1200	
5.	AA 109			23,100	1430	
6.	AA 145			22,700	1400	
1.	A 87	-320	L	23,900	1480	1,830,000
2.	A 69-4		T	14,300	880	304,000
3.	A 70-1		T	13,000	810	400,000
4.	AA 151		L	17,600	1090	118,300
5.	AA 157		L	26,500	1650	1,200,000
6.	AA 164		L	19,400	1200	61,940
1.	A 66	-200	T	16,700	1040	638,000
2.	A 31-6		T	13,800	860	149,000
3.	A 69-2		T	7,400	670	74,600
4.	A 69-5		T	11,800	730	251,000
5.	AA 150		L	16,600	1030	800,000
6.	AA 160		L	23,700	1470	177,500
1.	A 25	-100	L	18,800	1170	45,000
2.	A 69-1		T	6,850	420	54,500
3.	A 69-3		T	10,100	625	73,300
4.	AA 158		L	20,400	1260	98,500
5.	AA 165		L	12,000	750	47,400
6.	AA 168		L	15,000	930	46,000
**1.	A 31	RT	T	18,700	1160	58,400
2.	A 61		T	11,400	1140	50,000
3.	A 67		T	16,320	1010	42,900
4.	AA 142		L	22,200	1380	80,000
5.	AA 148		L	16,000	990	54,200
6.	AA 153		L	16,100	1000	86,900
1.	A 4-2	+200	L	19,300	1200	23,800
2.	A 24		L	17,600	1100	32,400
3.	A 63-1		T	14,400	890	27,400
4.	AA 149		L	12,400	770	32,100
5.	AA 166		L	12,100	750	47,800
6.	AA 167		L	12,800	800	33,500
1.	A 16	+500	L	7,630	470	60,100
2.	A 31-5		T	5,900	360	40,400
3.	A 31-8		T	4,800	300	13,200
4.	AA 102		L	6,300	390	13,200
5.	AA 147		L	8,370	520	38,800
6.	AA 163		L	8,700	540	29,300
1.	A 4-1	+600	L	4,000	250	
2.	A 31-9		L	2,760	170	
3.	A 86		L	4,180	260	Not Determined
4.	AA 152		L	3,070	310	
5.	AA 169		L	2,870	180	
6.	A 62-1		T	3,150	190	

*Center span loading was used for tests at -423°F and 4 point for all others.

**The specimen below is of the same type as above except adhesively bonded with FM-1000 and tested at room temperature.

7005-1		T		720	20,600

TABLE 19

FLEXURE TESTS* - SANDWICH SPECIMENS B & BB

Faces: X7106

Core: 6951, type 6-80 x ½", Modified Square Cell

Brazing Alloy: 716

	SPECIMEN NUMBER	TEST TEMP. °F	CORE DIRECTION	FACING STRESS AT CORE OR BRAZE FAILURE PSI	CORE SHEAR STRESS PSI	CORE SHEAR MODULUS PSI
1.	B 4	-423		9,700	600	
2.	B 129			7,600	470	
3.	B 133			9,200	570	Not Determined
4.	BB 64			9,500	590	
5.	BB 65			10,000	630	
6.	BB 70			10,000	630	
1.	B 6	-320	L	11,090	690	48,200
2.	B 9		L	10,350	640	299,600
3.	B 13-1		L	11,020	680	110,300
4.	BB 7		L	12,560	780	Not Determined
5.	BB 50		L	13,480	840	85,700
1.	B 10	-200	L	9,780	600	135,800
2.	B 13-2		L	10,960	680	140,300
3.	B 47		L	7,590	470	55,900
4.	BB 41		L	11,640	720	32,400
5.	BB 62		L	11,700	720	37,200
1.	B 2	-100	L	10,350	640	18,500
2.	B 45		L	8,630	530	29,100
3.	B 49		L	7,660	480	12,300
4.	BB 9		L	5,670	350	15,800
5.	BB 11		L	15,160	940	25,000
6.	BB 119		L	8,510	530	92,700
** 1.	B 44	RT	L	8,300	510	7,660
2.	B 51		L	6,440	400	4,650
3.	BB 5		L	9,850	620	7,140
4.	BB 13		L	6,220	390	6,100
5.	BB 43		T	9,550	600	
6.	BB 114		L	9,780	630	6,730
1.	B 42	-200	L	8,800	550	31,000
2.	B 46		L	5,920	370	17,500
3.	BB 6		L	9,550	592	45,700
4.	BB 8		L	9,300	580	41,700
5.	BB 113		L	9,200	570	32,000
1.	B 130	-500	L	4,660	290	25,800
2.	B 134		L	5,560	340	16,000
3.	BB 61		L	6,080	380	28,700
4.	BB 71		L	5,900	370	20,800
1.	B 125	+600	L	2,060	130	5,880
2.	B 126		L	2,540	150	10,200
3.	BB 97		L	1,540	95	3,330
4.	BB 118		L	2,600	160	6,200

*Center Span loading was used for tests at -423°F and 4 point for all others.

**Additional brazed specimens tested at room temperature.

B-60-1	L	390	12,900
B-60-2	L	400	11,300
B-60-3	L	430	14,200

Same type specimen except adhesively bonded with FM1000.

6951-1	L	390	31,900

TABLE 20

FLEXURE TESTS* - SANDWICH SPECIMENS C & CC

Faces: 7039

Core: 6951, type 6-80 x ½", hexagonal cell

Brazing Alloy: 719

	SPECIMEN NUMBER	TEST TEMP. °F	CORE DIRECTION	FACING STRESS AT CORE OR BRAZE FAILURE PSI	CORE SHEAR STRESS PSI	CORE SHEAR MODULUS PSI
1.	C 8	-423		12,600	780	
2.	C 16			11,300	700	
3.	C 75			18,500	1,150	
4.	C 130			16,000	990	Not Determined
5.	CC 31			12,400	1,120	
6.	CC 86			12,200	1,100	
1.	C 81	-320	L	6,330	390	69,000
2.	C 84		L	11,180	690	101,000
3.	C 114		L	16,180	1,000	
4.	CC 43		L	13,330	1,200	187,700
5.	CC 99		L	11,450	1,030	116,000
6.	CC 102		L	11,480	1,030	166,000
1.	C 76	-200	L	14,390	890	96,700
2.	C 89		L	16,780	1,030	47,200
3.	C 90		L	11,820	730	130,900
4.	C 92		L	8,360	520	217,900
5.	CC 30		L	12,960	1,170	102,500
6.	CC 36		L	13,260	1,190	149,200
1.	C 15	-100	L	13,300	830	
2.	C 133		L	13,170	470	
3.	C 139		L	7,800	520	
4.	CC 34		L	11,500	1,040	Not Determined
5.	CC 44		L	11,300	1,020	
6.	CC 100		L	9,410	840	
** 1.	C 110	RT	L	4,700	290	
2.	C 111		L	10,950	680	
3.	C 142		L	13,450	840	
4.	CC 29		L	11,300	1,020	Not Determined
5.	CC 37		L	8,980	810	
6.	CC 90		L	8,720	790	
1.	C 9	+200	L	14,720	920	31,770
2.	C 109		L	7,540	470	11,110
3.	C 136		L	10,900	670	16,200
4.	CC 47		L	9,370	840	25,000
5.	CC 50		L	7,260	650	18,000
6.	CC 103		L	10,310	930	23,200
1.	C 18	+500	L	7,550	470	21,350
2.	C 77		L	6,630	410	54,650
3.	CC 33		L	6,670	600	19,800
4.	CC 88		L	6,790	610	26,500
5.	CC 98		L	6,760	610	23,040
1.	C 11	+600	L	2,600	160	7,900
2.	C 113		L	2,860	180	9,050
3.	CC 91		L	2,500	230	6,250
4.	CC 97		L	2,480	220	7,900
5.	CC 105		L	2,090	190	5,040

*Center span loading was used for tests at -423°F and 4 point for all others.

**Additional brazed specimens tested at room temperature.

CC-87	L	1120	86,000
CC-101	L	950	80,000

** Same type specimen except adhesively bonded with FM1000.

6951-2	L	550	21,000

TABLE 21

PLATE CORE SHEAR TESTS - SANDWICH SPECIMENS A & AA

NOMINAL SPECIMEN SIZE: 0.6" x 1" x 6"

(The core on the 2" specimen width was milled to 1" to prevent adhesive failure between the specimen faces and the fixture.)

Faces: X7005

Core: X7005 type 6-80 x ½", hexagonal cell

Brazing Alloy: 719

	SPECIMEN NUMBER	TEST TEMPERATURE °F	CORE DIRECTION	ULTIMATE CORE SHEAR STRESS psi	CORE SHEAR MODULUS psi
1.	A23	-423		1,260	
2.	AA59			1,190	
3.	AA62			1,140	
4.	AA63			1,200	
5.	AA110			1,140	
6.				1,150	
1.	A15	-320		1,030	
2.	AA64			1,140	
3.	AA108			950	
1.	A31-2	-200		600	
2.	AA58			985	
3.	AA65			830	
1.	A3	-100		845	
2.	AA105			810	
3.	AA193			945	
1.	A36	RT	T	430	65,000
2.	A67		T	700	59,000
3.	A73-1		T	500	24,600
4.	A144		L	770	150,000
5.	AA107		L	1,060	106,000
6.	AA144		L	770	203,000
1.	A108	+200		710	
2.	AA66			710	
3.	AA70			700	
4.	AA112			710	
1.	A110	500		330	
2.	AA68			310	
3.	AA103			250	
1.	A35	600		190	
2.	A41			230	
3.	AA106			170	

TABLE 22

PLATE CORE SHEAR TESTS - SANDWICH SPECIMENS B & BB

NOMINAL SPECIMEN SIZE: 0.6" x 2" x 6"

Faces: X7106

Core: 6951 type 6-80 x ½", square cell

Brazing Alloy: 716

	SPECIMEN NUMBER	TEST TEMPERATURE °F	CORE DIRECTION	ULTIMATE CORE SHEAR STRESS psi	CORE SHEAR MODULUS psi
1.	B7	-423		356	
2.	B50			313	
3.	B136			464	
4.	BB54			474	
5.	BB60			509	
6.	BB112			508	
1.	B1	-320		445	
2.	B3			485	
3.	B20			172	
1.	B135	-200		390	
2.	BB52			330	
3.	BB107			73	
1.	B12	-100		345	
2.	BB10			382	
3.	BB49			360	
1.	B200	RT	L	345	53,000
2.	B201		L	288	93,000
3.	B202		L	360	93,000
4.	BB52		L	240	122,000
1.	B8	+200		260	
2.	B82			230	
3.	B203			305	
4.	B204			315	
1.	B59	+500		70	
2.	BB42			165	
3.	BB96			145	
4.	BB117			170	
1.	B52	+600		80	
2.	B132			150	
3.	BB12			90	

TABLE 23

PLATE CORE SHEAR TESTS - SANDWICH SPECIMENS C & CC

NOMINAL SPECIMEN SIZE: 0.6" x 2" x 6"

Faces: 7039

Core: 6951 type 6-80 x ½", Hexagonal cell

Brazing Alloy: 719

	SPECIMEN NUMBER	TEST TEMPERATURE °F	CORE DIRECTION	ULTIMATE CORE SHEAR STRESS psi	CORE SHEA MODULUS psi
1.	C7	-423		921	
2.	C74			894	
3.	C88			765	
4.	CC48			434	
5.	CC85			671	
6.	CC89			624	
1.	C83	-320		10	
2.	CC96			70	
1.	C112	-200		200	
2.	C115			280	
3.	CC92			620	
1.	C82	-100		94	
2.	C146			500	
3.	CC32			640	
1.	C19	RT	L	410	90,000
2.	C119		L	480	102,000
3.	CC28		L	530	77,000
4.	CC46		L	550	107,000
1.	C12	+200		170	
2.	C17			330	
3.	C91			270	
4.	CC35			350	
5.	CC49			370	
1.	C10	+500		148	
2.	CC45			290	
1.	C85	+600		160	
2.	C86			150	
3.	CC84			140	

Table 24

Room Temperature Flatwise Tensile Tests of Honeycomb Core Sandwiches Adhesive Bonded with FM 1000

Core Material	Core Type	Flatwise Tensile Strength psi	Failure Mode
6951	6-80 x ½" square cell	460	Core Tear
6951	6-80 x ½" hexagonal cell	550	20% Core Tear 80% Core-to-face adhesion
X7005	6-80 x ½" hexagonal cell	830	100% core-to-face adhesion

2.2 QUENCHING AND TOOLING DEVELOPMENT FOR LARGE (CURVED) PANELS

This section presents the brazing tooling and quenching system studies. Initial evaluations of quenching media and brazing tooling were performed in brazing flat panels having X7106 faces, 6951 core, and the No. 716 brazing alloy. Minimum distortion quenching procedure using liquid nitrogen were developed. Two large size cylindrical section brazements approximately 30" long were successfully fabricated from X7106 alloy facings, No. 22 brazing sheet core, and the No. 719 brazing alloy. These panels were furnace brazed and liquid nitrogen quenched with minimal distortion. Evaluation of braze quality included ultrasonic and radiographic methods. The general limits of these non-destructive inspection methods were defined. Both of these systems were shown to be superior to thermographic and isotope radiographic inspection.

2.2.1 Quenching and Tooling Tests

Brazing process development was combined with tooling development. The first step was fabrication of two 18" x 18" egg-crate type quenching fixtures; one of stainless steel, the other of "Transite".* These fixtures are shown in Figures 30 and 31, after quenching from 1000°F into room temperature water.

Although brazements were water quenched initially, the continuing literature survey uncovered a paper by E. Dullberg** which described the results obtained by quenching aluminum alloy parts in liquid nitrogen rather than water. Welded assemblies and stamped sheet metal parts were free from distortion and residual-stress after quenching in liquid nitrogen. Identical parts, quenched in water, were badly distorted.

*"Transite" is a Johns-Manville asbestos cement sheet.

**"Cryogenics for Distortionless Heat Treating", E. Dullberg, Grumman Aircraft Engineering Corp., SAE paper 844c, April, 1964.

"Cryogenics Squelch Quench Distortion", E. Dullberg, SAE Journal, August, 1964, p. 86-88.

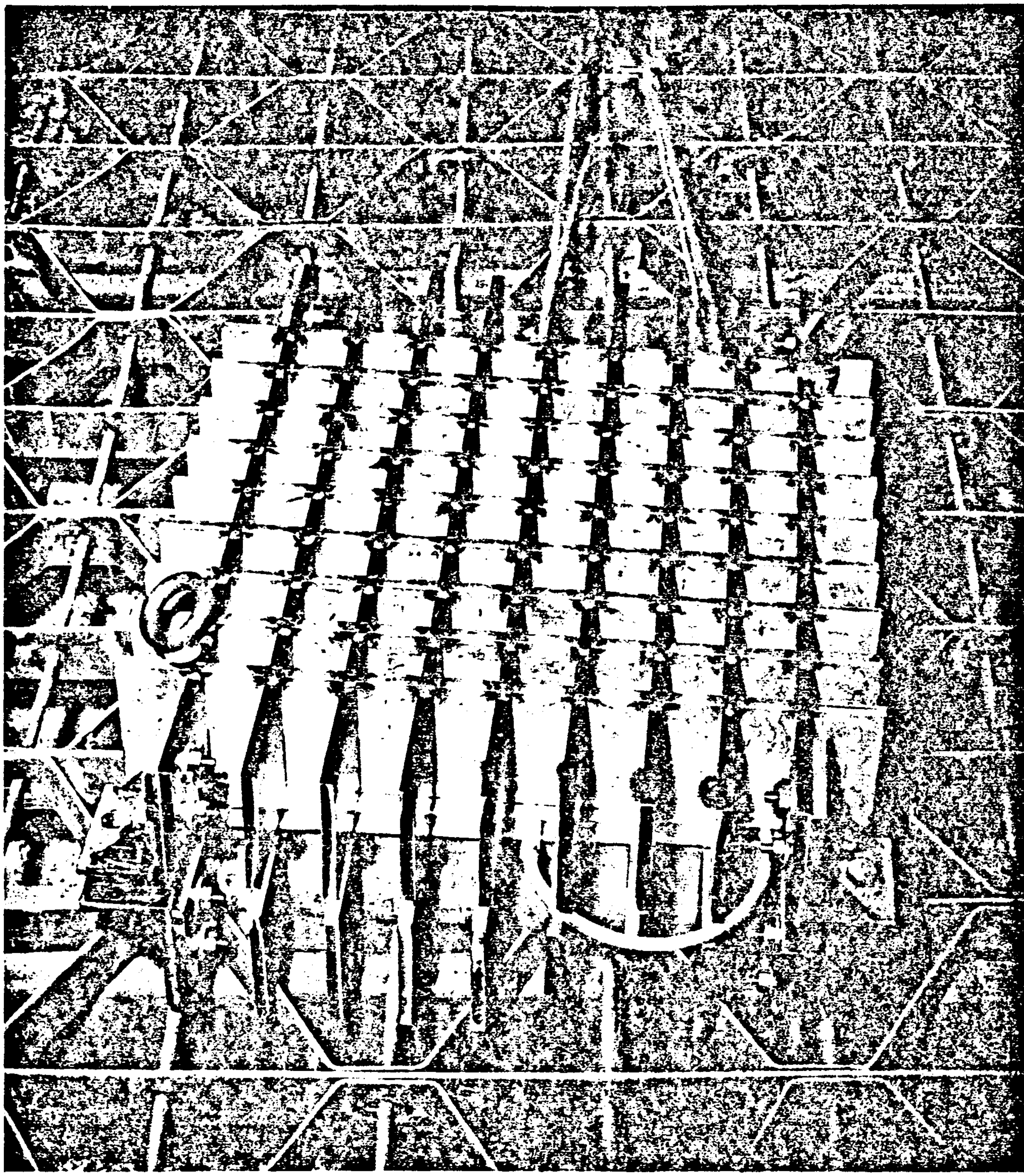


Figure 30 Stainless Steel Egg-Crate Fixture Used for Water Quenching Aluminum Retort.

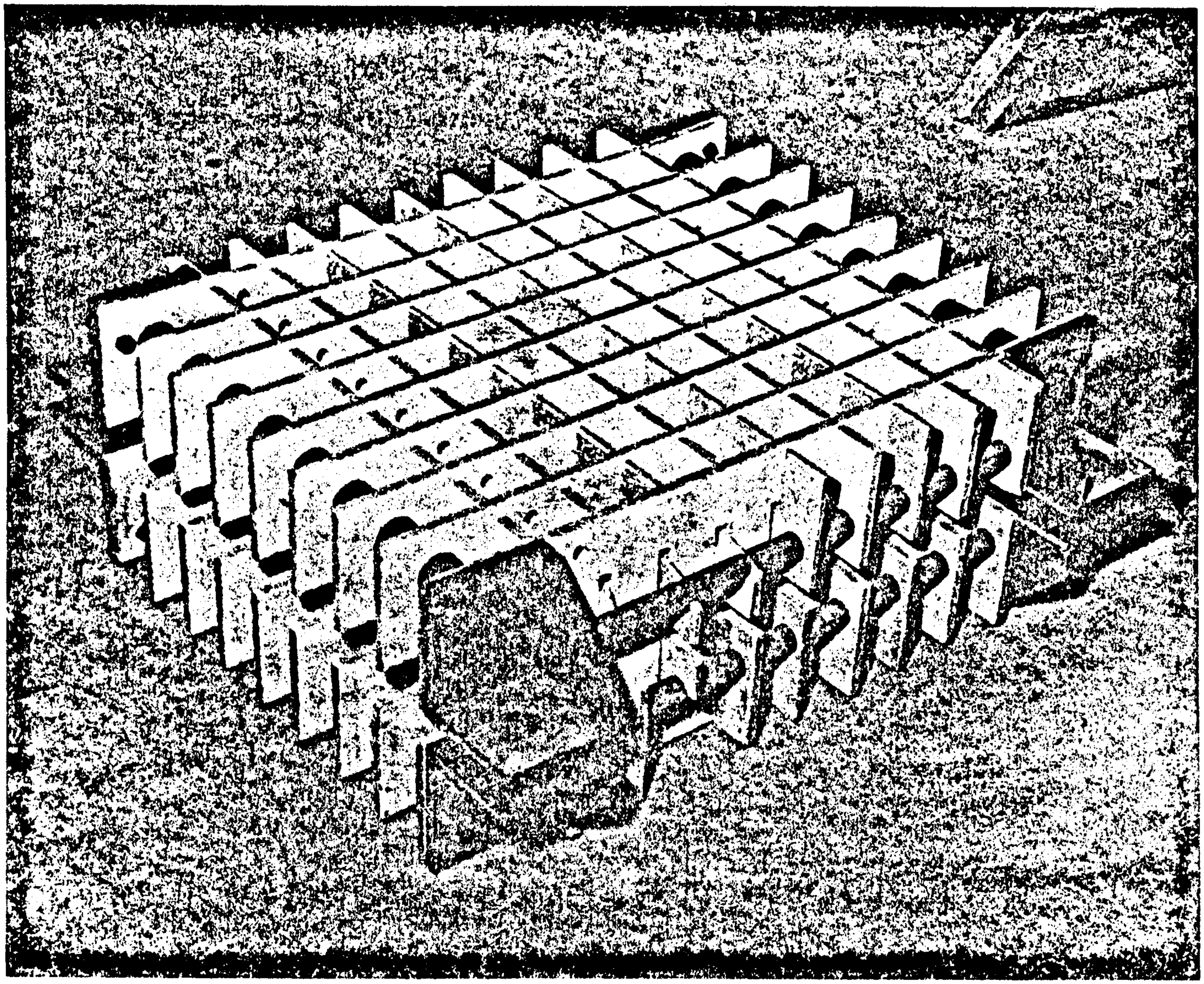


Figure 31 'Transite' Egg-Crate Fixture Used for Water Quenching Aluminum Retort.

Consequently, the three quenching media which were evaluated were water, liquid nitrogen and air.

Prior to sandwich brazing and quenching, a test was conducted on portions of sandwich panel "B".

Identical specimens from the same portion of panel B were solution heat treated at 900°F in air. One specimen then was quenched in room temperature water; the other in liquid nitrogen. No apparent difference was noted and neither sandwich specimen was distorted. The specimens are shown in Figure 32. Sheet metal specimens, tested earlier in the program (in contrast to a stabilized sandwich), were distorted when quenched in water.

The specimens (X7106 faces brazed to 6951 core with the No. 716 alloy) then were aged 48 hrs. at 250°F. Tensile specimens from the faces were tested at room temperature. The following data were obtained:

Specimen No.	Quench Media	Tensile Strength KSI	Yield Strength KSI	Elongation Percent
W-1	Water	58.0	49.5	13
W-2	Water	58.9	50.3	15
W-3	Water	58.2	50.5	12
W-4	Water	58.4	48.0	12
N-5	Liq. N_2	58.0	Not Determined	12
N-6	Liq. N_2	58.2	48.4	13
N-7	Liq. N_2	58.5	48.5	15
N-8	Liq. N_2	58.4	47.1	13

Next, the steel and transite quenching fixtures were used to quench brazing loads into room temperature water.

The stainless steel fixture retained flatness and was unaffected by quenching. Some cracking of the "Transite" fixture occurred, but the cracks apparently were caused by expansion of the tight fitting steel tie rods.

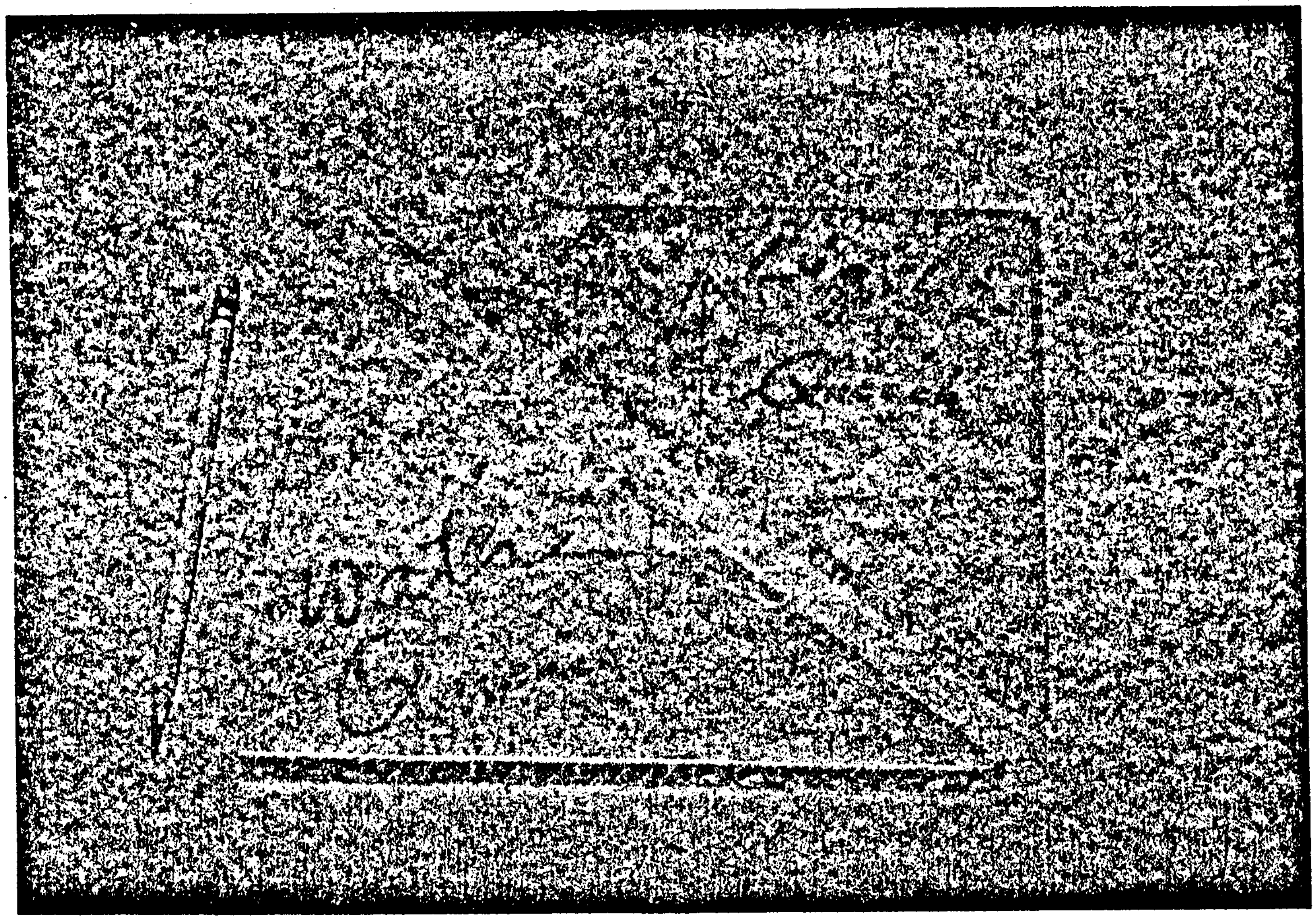


Figure 32 Two Sections of Panel B Solution Heat Treated at 900°F Followed by Quenching: One Quenched in Room Temperature Water; the Other, in Liquid Nitrogen. No Apparent Difference was Noted.

NOT REPRODUCIBLE

The brazing loads within the fixtures were comprised of 3003 aluminum alloy retort and various sandwich panels. During quenching, the retorts remained flat within the fixtures, but their tendency to distort coupled with restraint from the fixtures, caused core crushing of the panels within the retorts. In addition, the retorts distorted when they were removed from the restraining fixture. The third aluminum retort was quenched into liquid nitrogen without any fixturing and was relatively free from distortion. The three aluminum retorts are shown in Figure 32A.

Also quenched into liquid nitrogen were sheet aluminum specimens and a specimen of "Marinite".* These materials and retort No. 3 are shown in Figure 33 after quenching. The sheet aluminum did not distort and the "Marinite" was not damaged.

The 3003 aluminum alloy retorts caused unexpected problems. The first two apparently leaked during the brazing cycles. Following the brazes, the retorts were dye-checked and cracks were found. Retort No. 3 was dye-checked before and after brazing and found to be free of cracks. However, the aluminum tubes inadvertently were pulled off at approximately 1050°F. These were problems which could be prevented, but there did not appear to be a significant advantage in using aluminum retorts. The next retorts were to be fabricated from either carbon steel or stainless steel.

Two additional brazing loads were quenched into liquid nitrogen. Both retorts were flat and constructed of carbon steel. The steel retorts and panels within were relatively free from distortion, compared with steel retorts which had been water quenched. However, both carbon steel retorts cracked while submerged in the liquid nitrogen. Consequently, a 300 series stainless steel was used for the subsequent retorts.

*A Johns-Manville asbestos cement sheet, much like "Transite" except that it is lower in density and has higher temperature capabilities - rated to 1200°F by Johns-Manville.

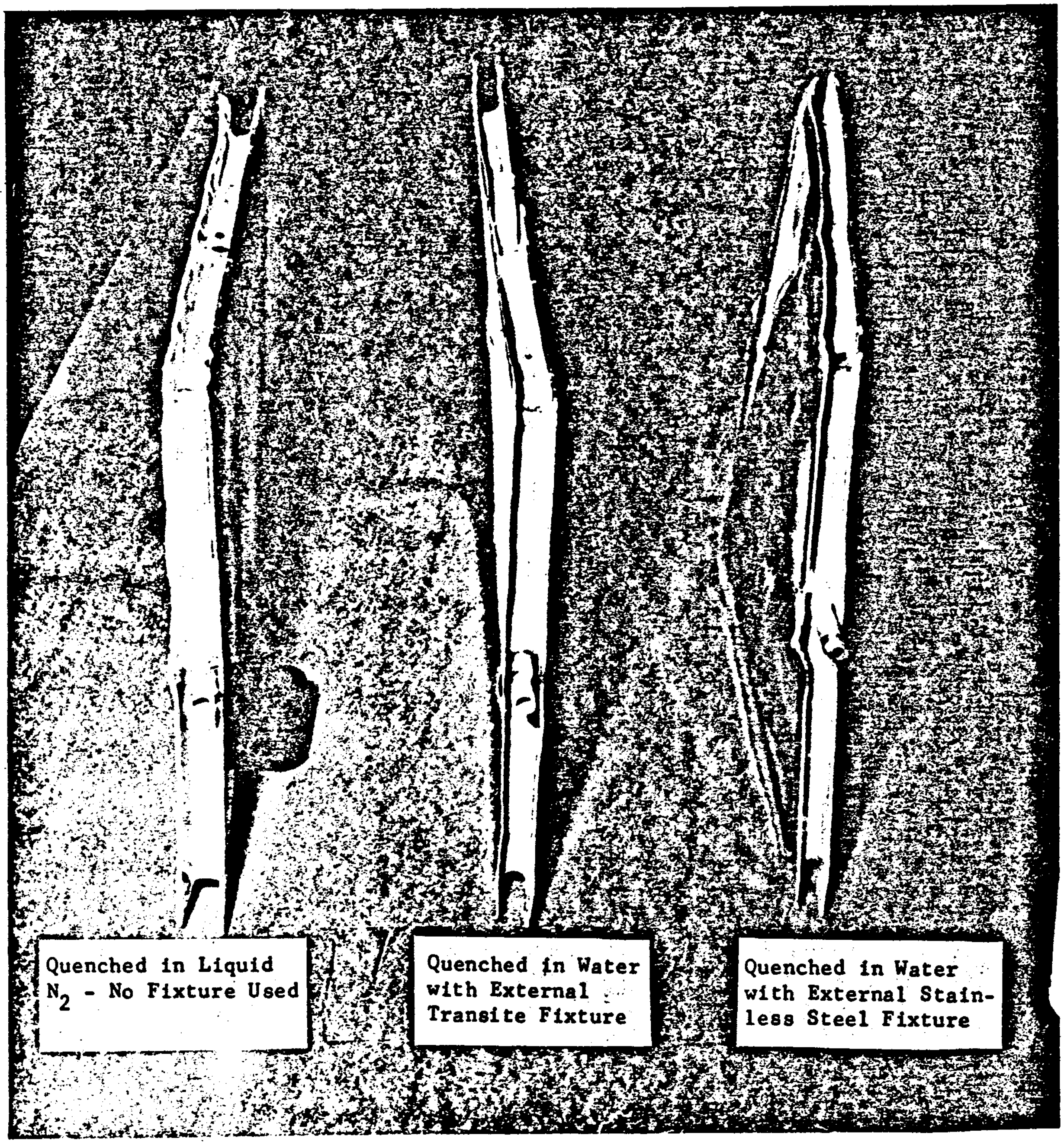


Figure 32A Aluminum Alloy 3003 Retorts Shown after Quenching from the Brazing Temperature.

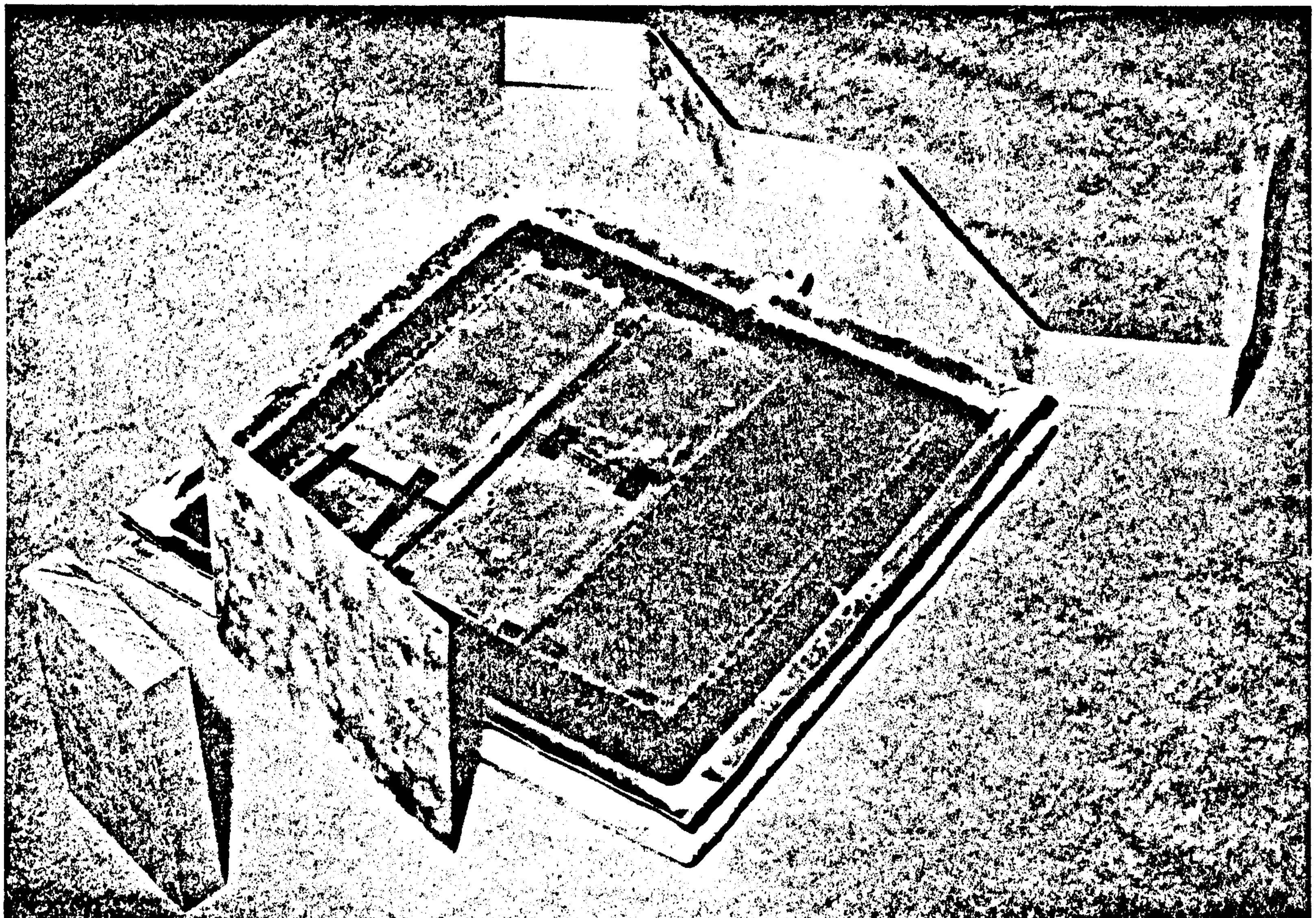


Figure 33 Retort No. 3 Shown after Quenching in Liquid Nitrogen. Sheet Aluminum and 'Marinite' Specimens also were Quenched into Liquid Nitrogen.

2.2.2 Cylindrical Section Brazements

The quenching study showed that sandwich panels could be quenched into liquid nitrogen without distorting, appreciably. A curved brazing fixture, suitable for a cylindrical section brazement was fabricated from "Marinite". Two views of the fixture are shown in Figures 34 and 35. The steps required to braze and quench a section of a cylinder are shown pictorially in the subsequent figures.

The brazements were comprised of .062" X7106 faces, .005" No. 719 brazing alloy and honeycomb core fabricated from No. 22 Brazing Sheet, type 6-100 x .6", resistance welded. The retort parts and panel parts were preformed and match fitted to the brazing fixture contour. The panel faces and brazing foil were cleaned by abrasion and degreased. The honeycomb core was machined flat by sanding and cleaned by degreasing.

One X7106 aluminum facing sheet was positioned in the retort and strips of brazing alloy foil were tack welded in place as shown in Figure 36. The brazing alloy foil had varying degrees of rolling defects as shown in Figure 36. An 0.050" 321 stainless steel buffer sheet had been placed between the X7106 panel facing and the retort. Next, the roller formed honeycomb core was positioned over the brazing alloy as shown in Figure 37. Thermocouple tubes (not shown) then were positioned into the ends of the panel to a depth of 2". A 2" trim line was planned for the full panel periphery. Brazing alloy foil then was stretched over the top facing sheet of panel and tack welded in place. After placing the top facing sheet over the core, another .050" buffer sheet was added and retort cover was welded in place.

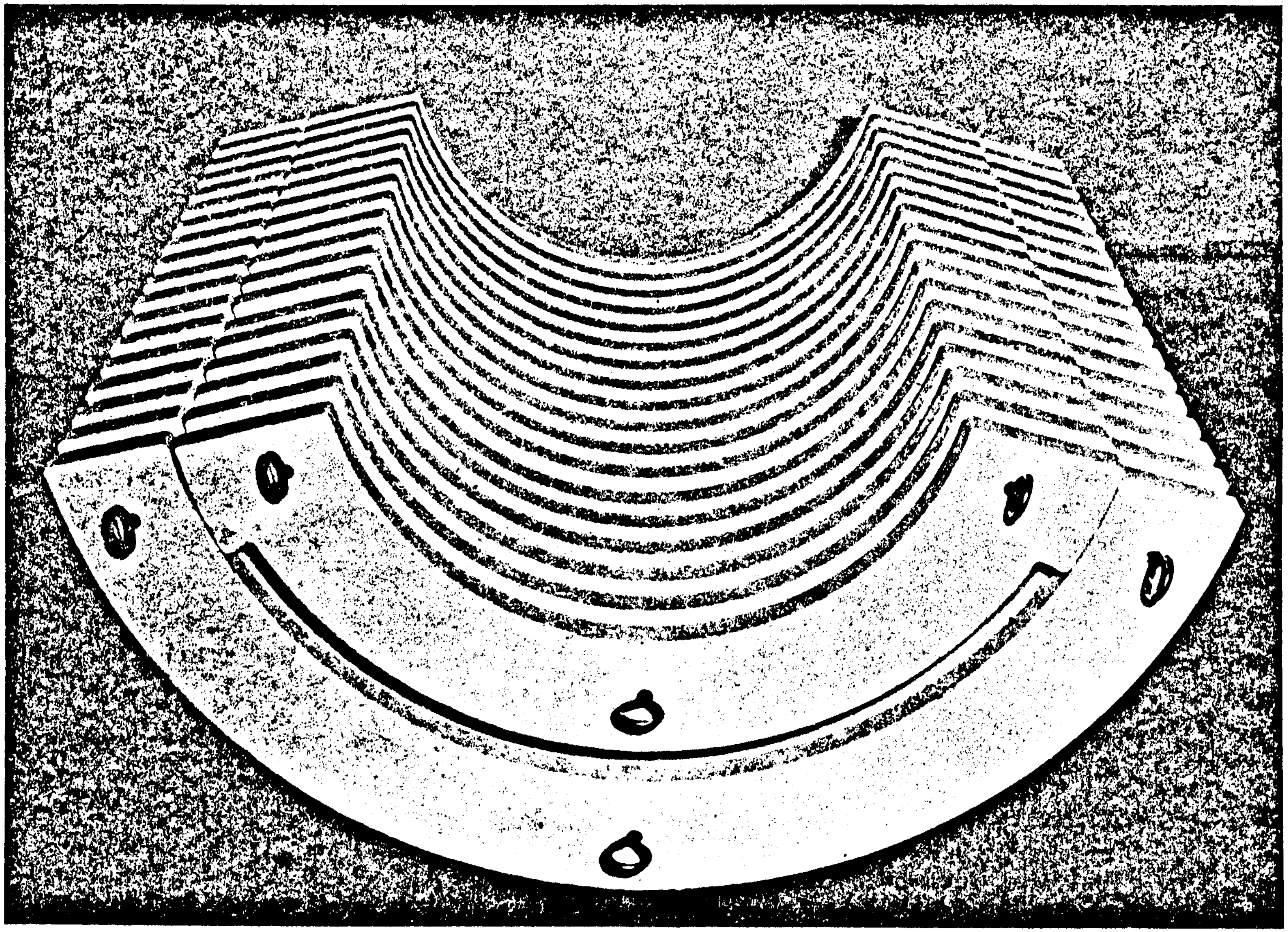


Figure 34 End View of External Brazing Fixture Constructed of 'Marinite'.

NOT REPRODUCIBLE

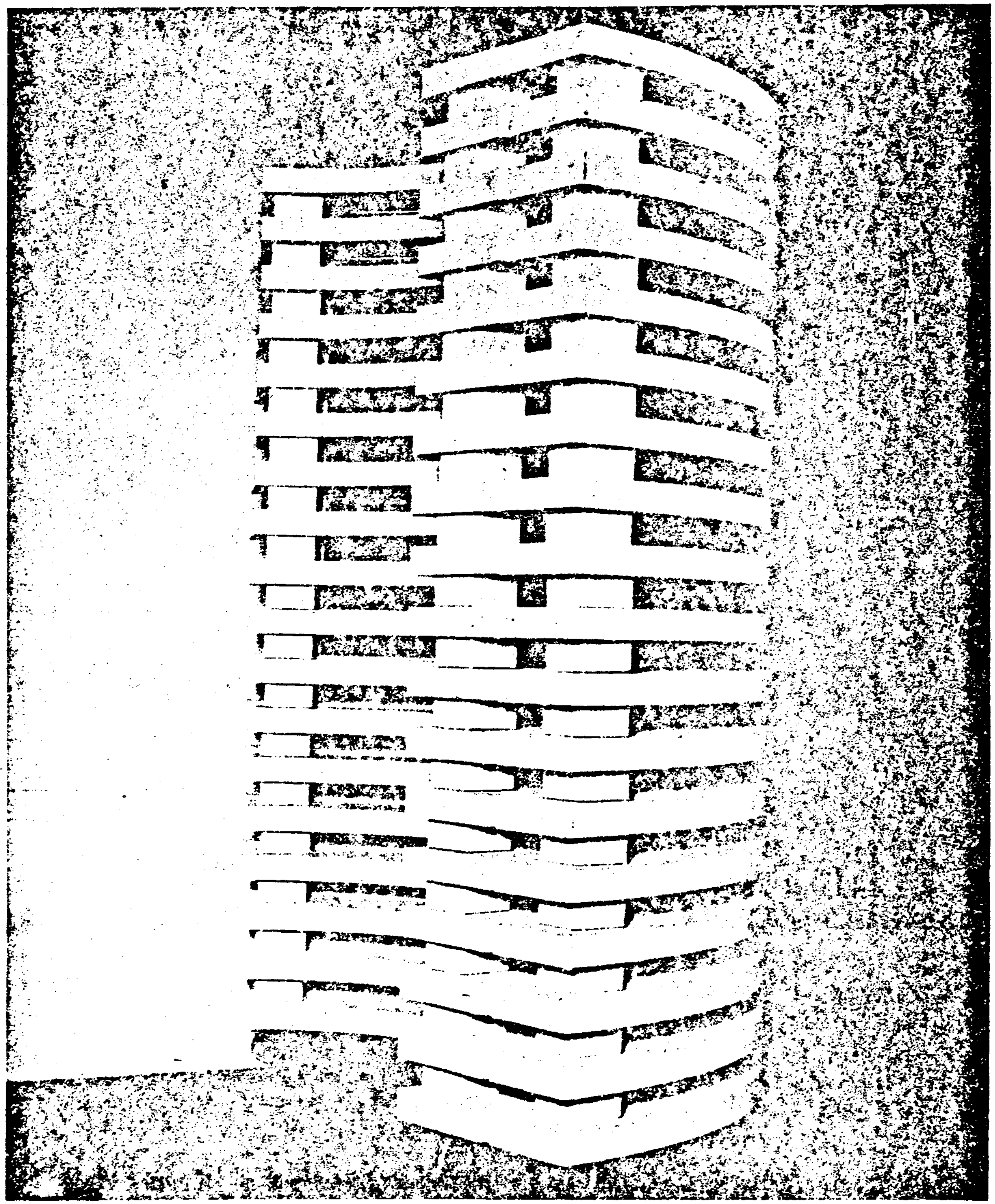


Figure 35 Side View of External Brazing Fixture.

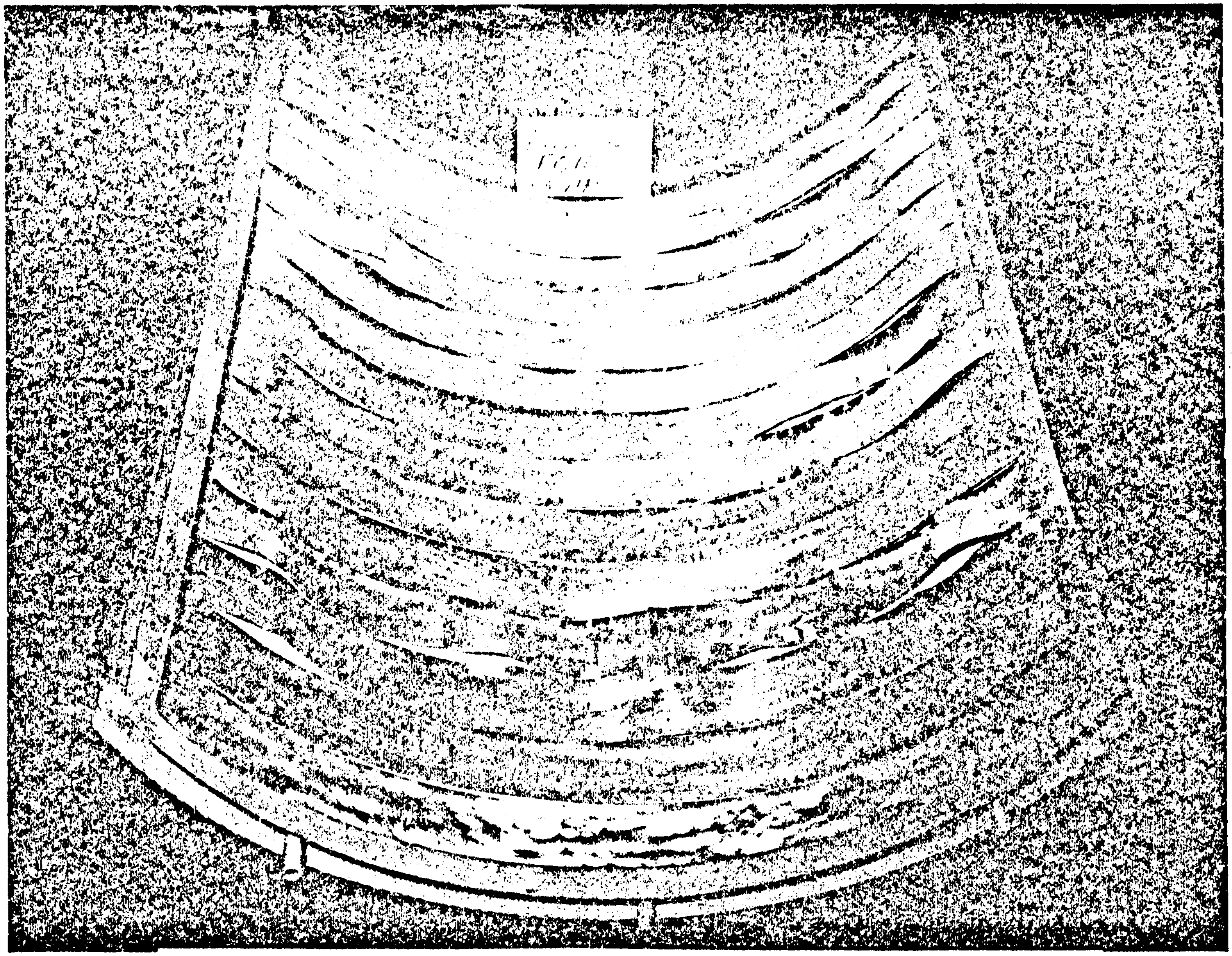


Figure 36 Number 719 Brazing Alloy Foil Positioned on the Concave Surface of the X7106 Panel Facing Sheet in Retort.

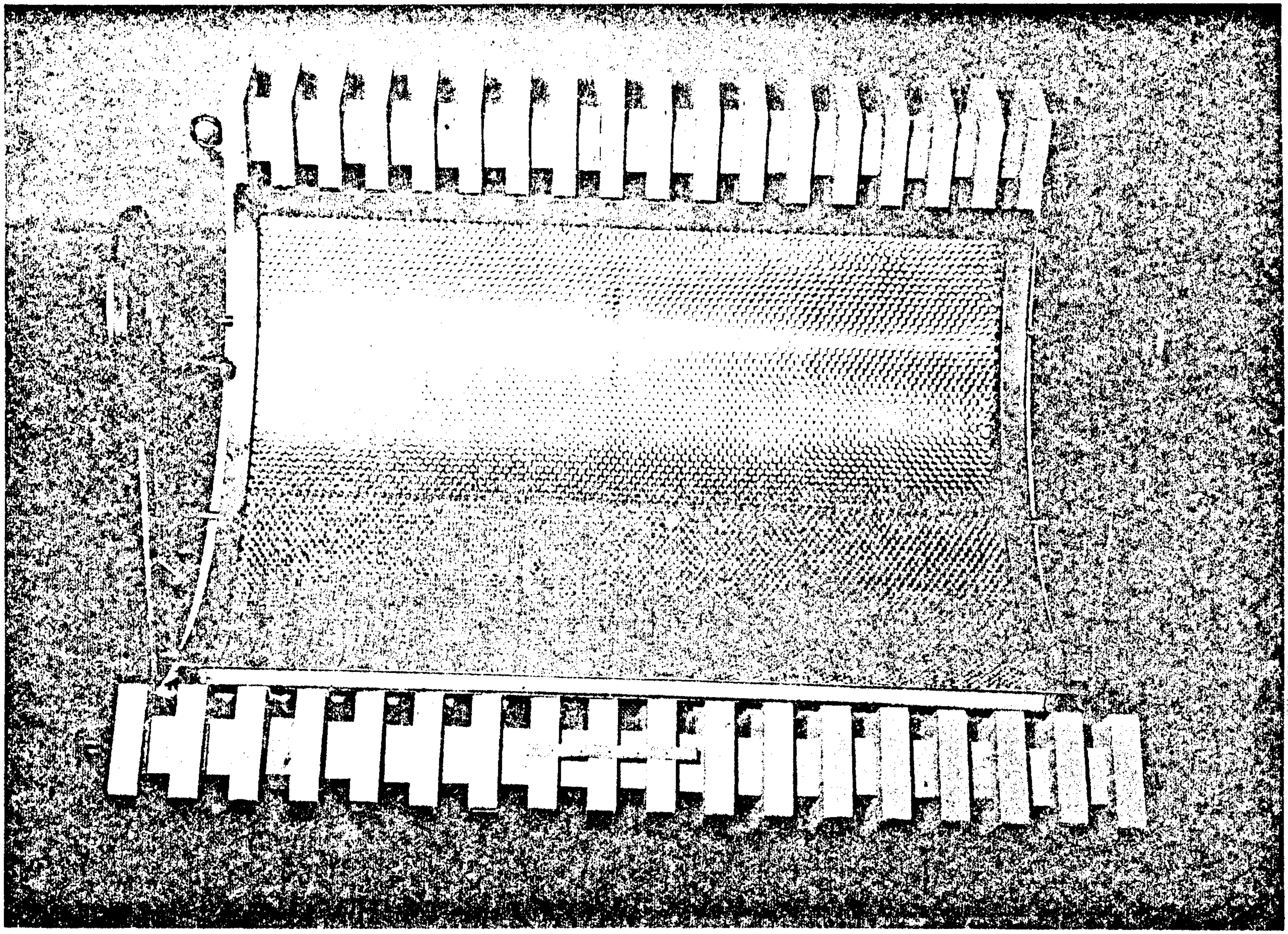


Figure 37 - Preformed Honeycomb Core Positioned over Brazing Alloy Foil in the Retort.

The top half of the brazing fixture was clamped in place and the retort was leak tested and purged by ten consecutive cycles of evacuation and back filling with argon. The vacuum line and argon flow then were regulated to provide an atmospheric clamping pressure of 0.3 psi on the retort.

The assembly was furnace brazed in an electrically heated circulating air furnace, preheated to 1000°F. It required 80 minutes to heat to brazing temperature range which was 1050° to 1070°F. Following brazing, the assembly was lowered out of the elevator furnace, rolled out from under the furnace, picked up with a crane, then submerged into a container of liquid nitrogen. These steps are shown in Figures 38 and 39. The part air cooled from 1050° to 900°F in 9 min.* At 900°F it was submerged into liquid nitrogen, then required 6 min. to reach 200°F. Within another 3 min. it was cooled to just below room temperature.

After stabilizing at -320°F, the fixture was withdrawn from the liquid nitrogen as shown in Figure 40. The retort and fixture are shown in Figure 41 after warming to room temperature. There was no apparent distortion or damage to either one. The brazed panel, after rough trimming, is shown in Figure 42. There appeared to be an edge bow of about 0.030", but the central portion was straight within .005".

Further visual and radiographic examination showed heavier fillets in the central portion than at panel edges indicating brazing alloy run-down and there were some face-to-core gaps at edges indicating lack of clamping pressure in those areas.

*900°F is above the minimum solution heat treatment temperature for X7106.

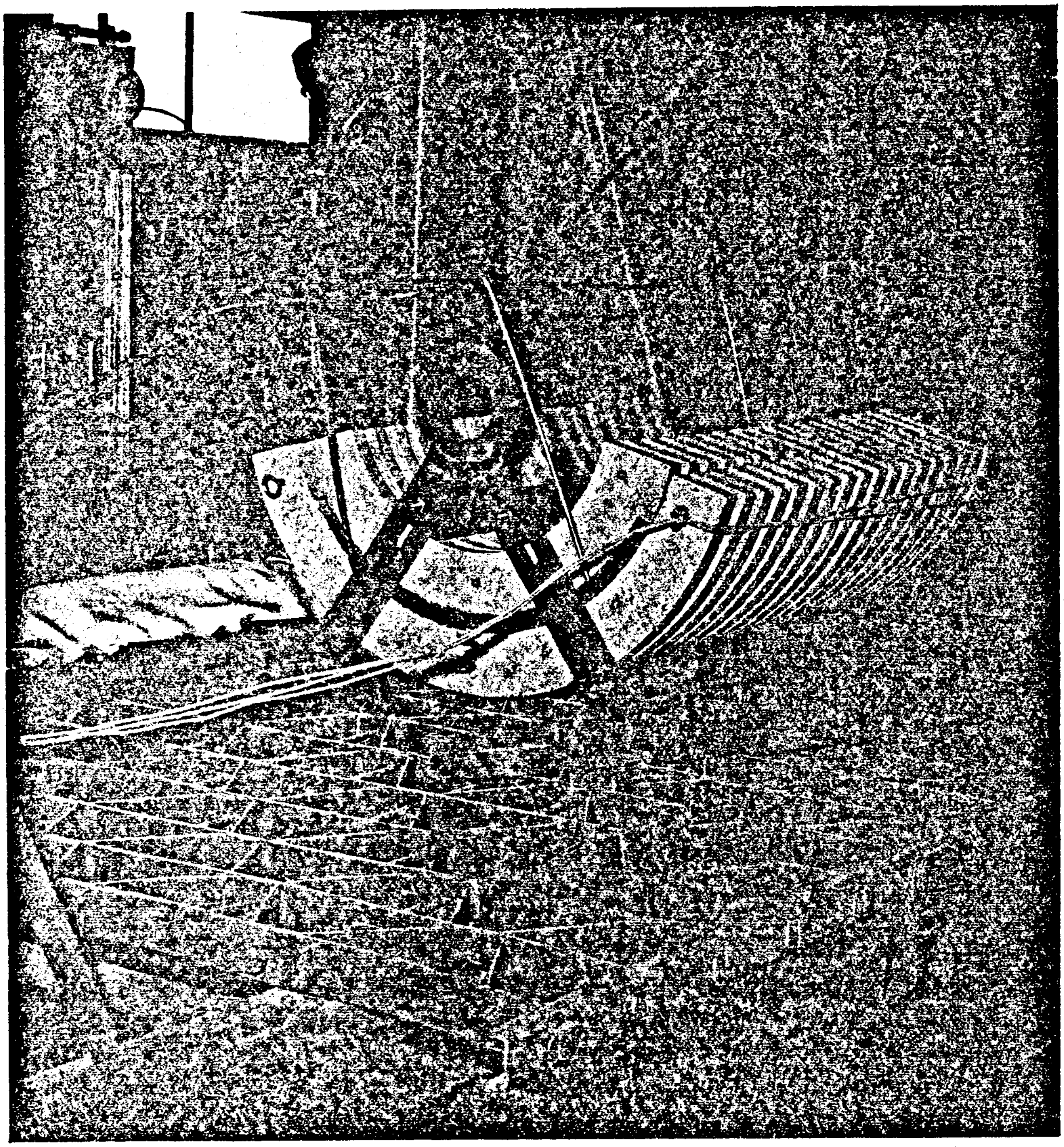


Figure 38 Brazing Fixture and Retort Rolling out From Under Furnace, Immediately Following Brazing.

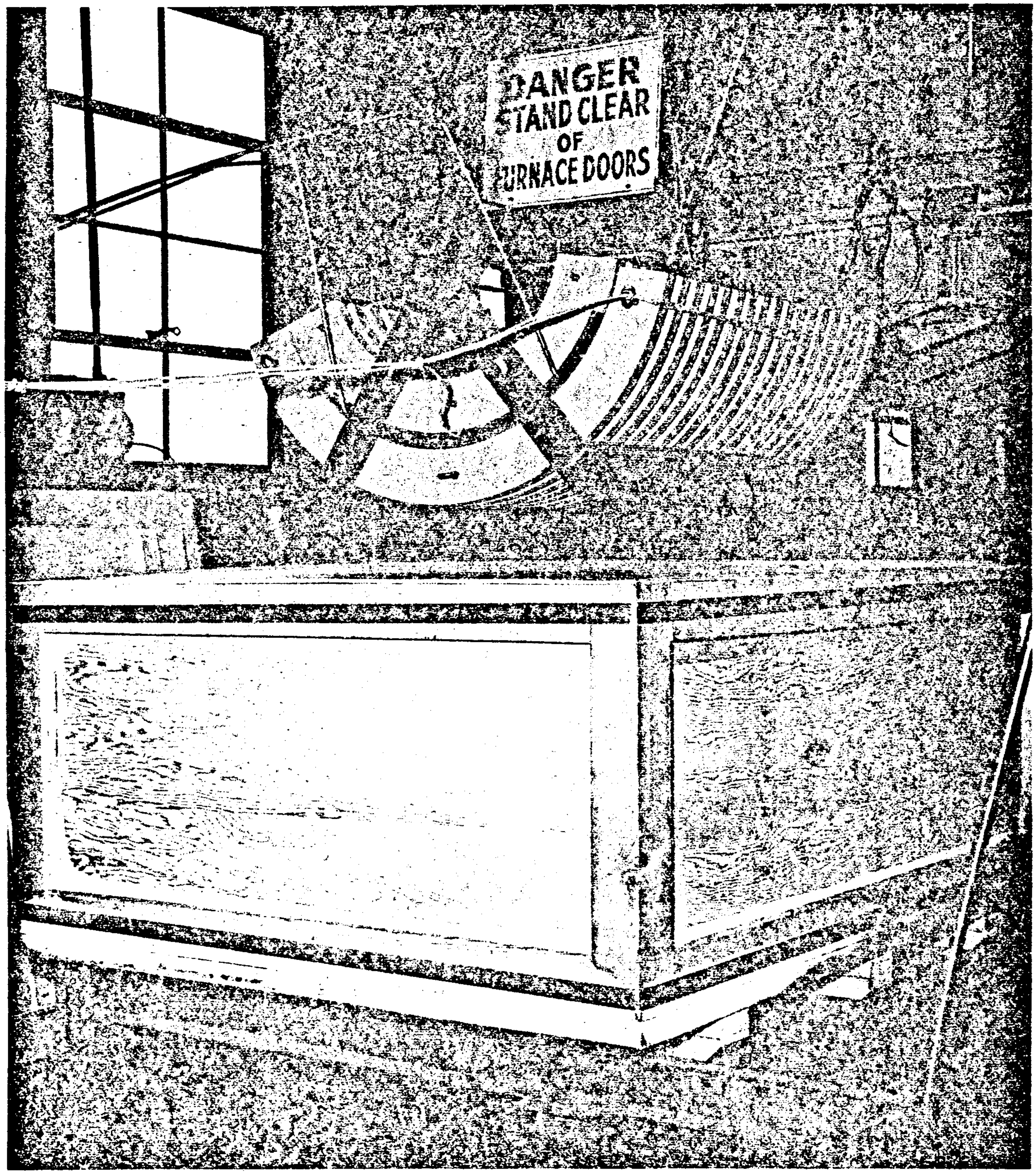


Figure 39 **Brazing Fixture and Retort Suspended over Container of Liquid Nitrogen.**

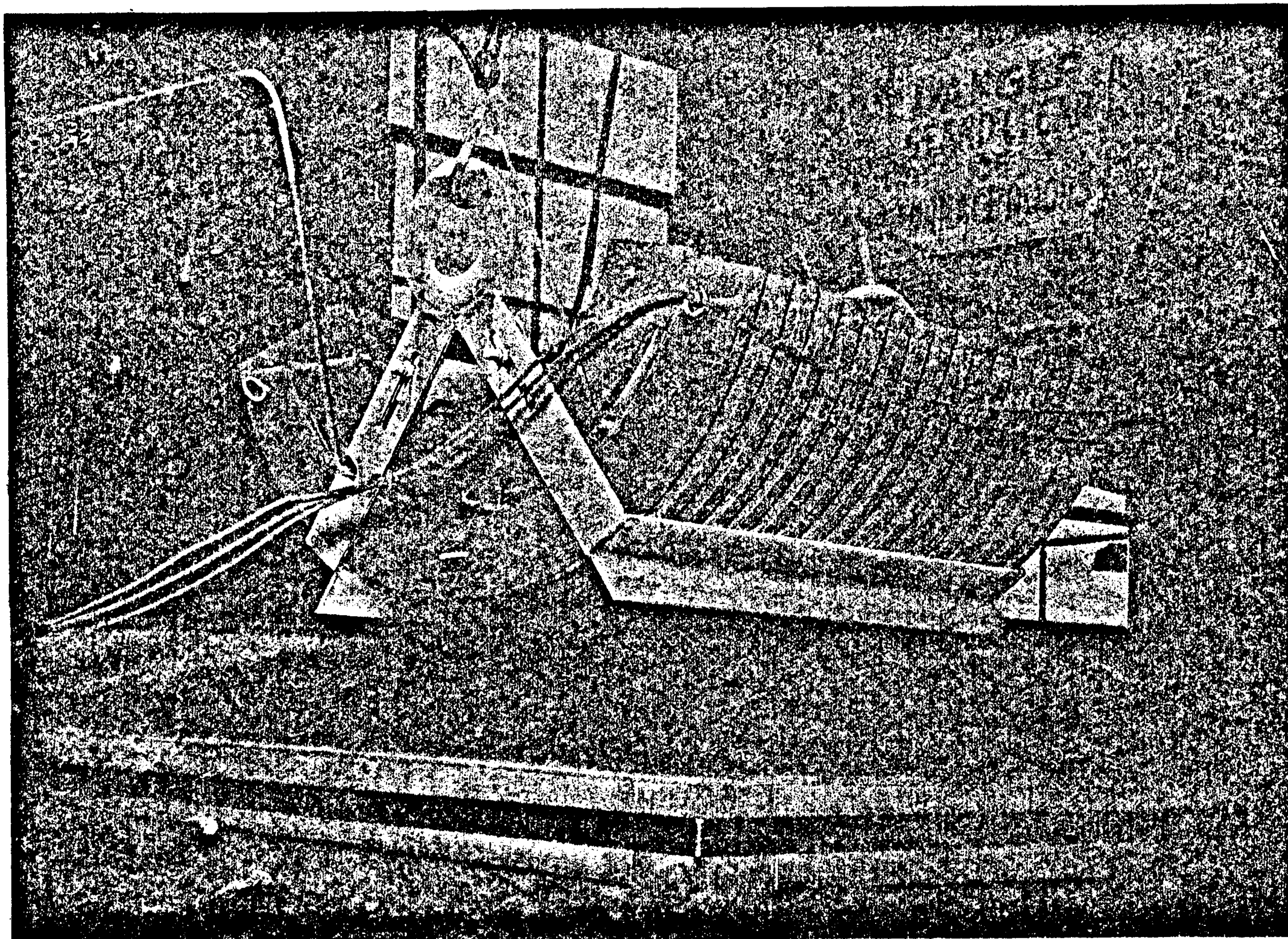


Figure 40 Brazing Fixture and Retort after Removing from Liquid Nitrogen.

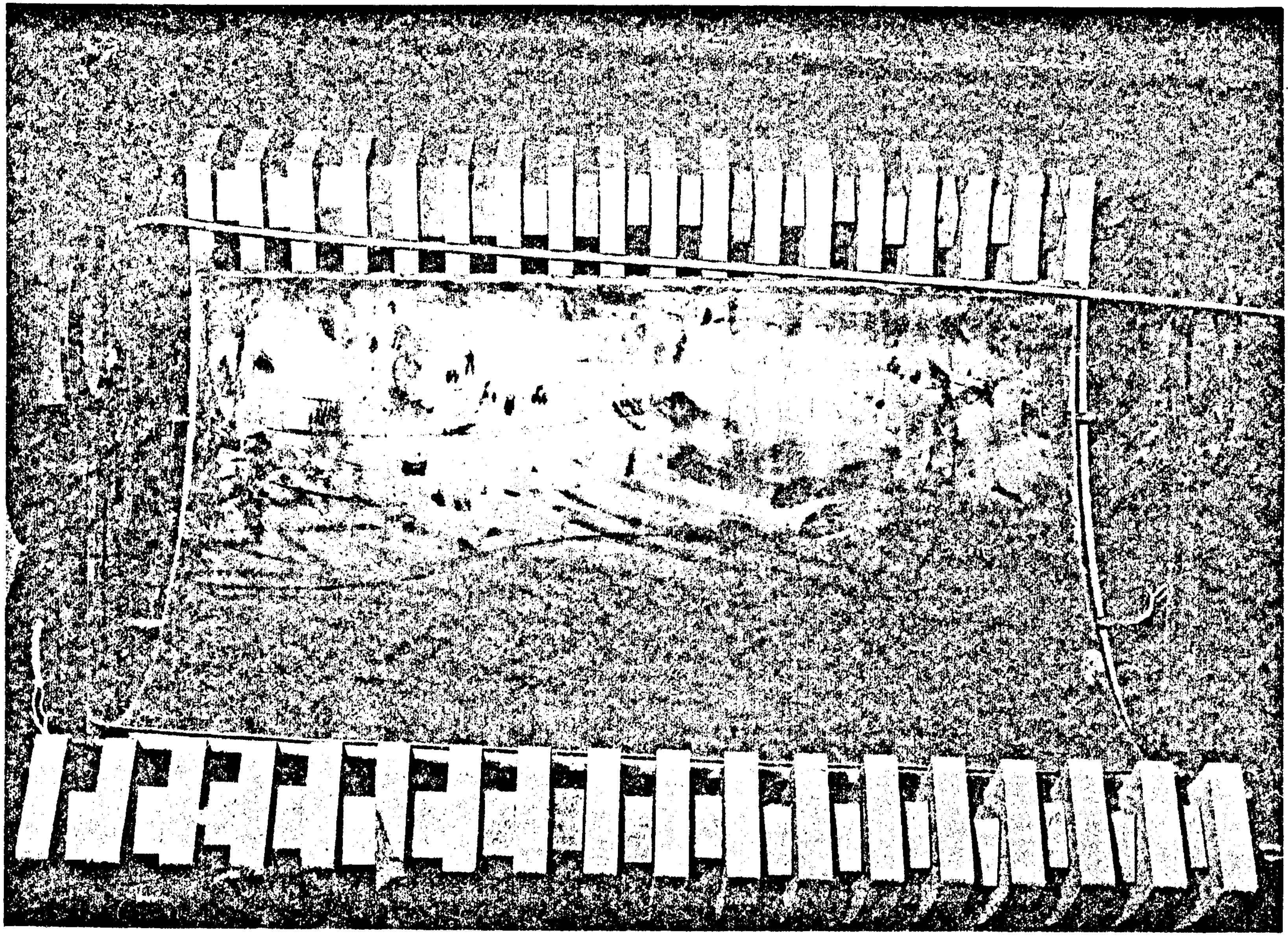


Figure 41 Retort and Half of Brazing Fixture Shown After Quenching into Liquid Nitrogen.

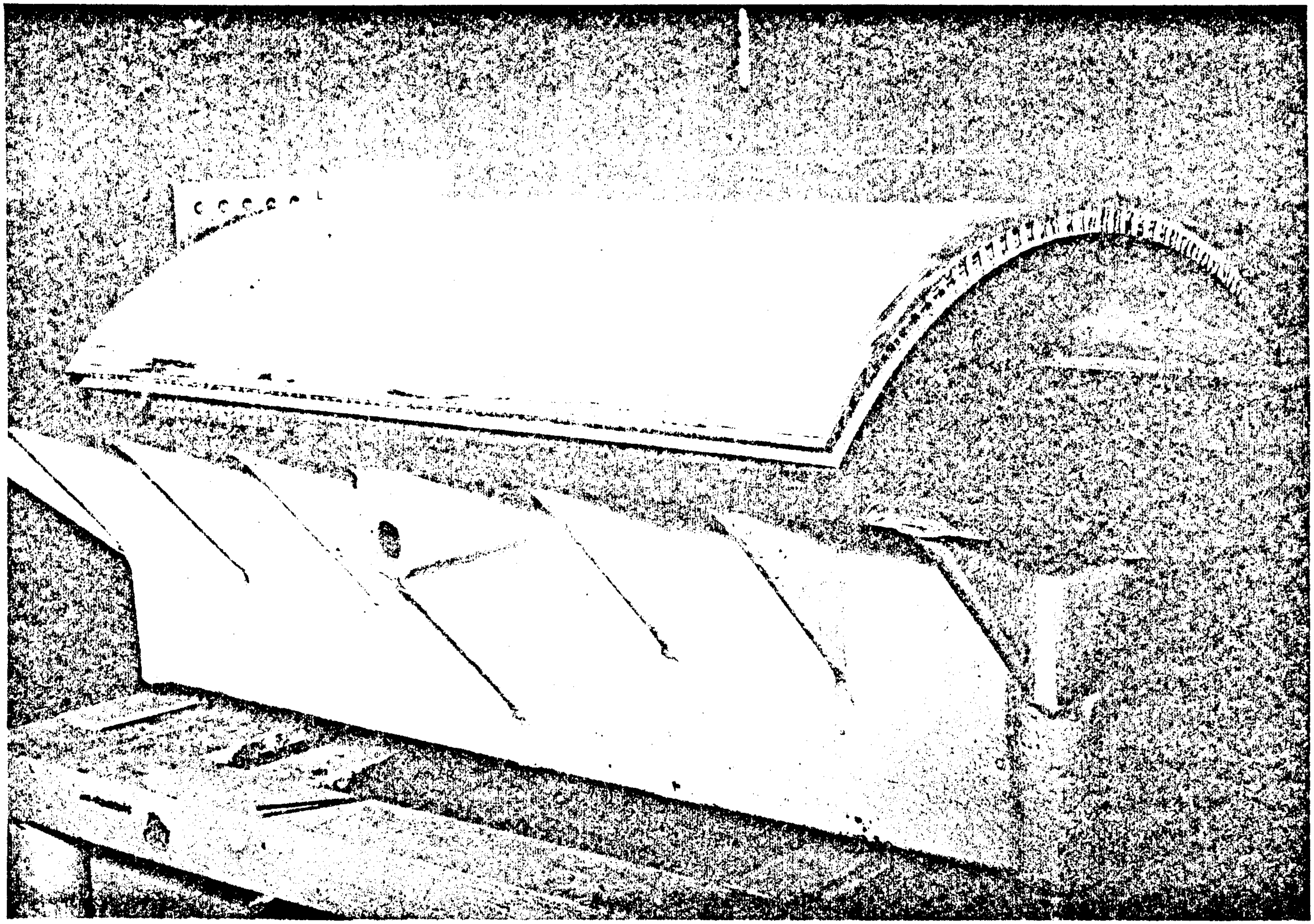


Figure 42 Brazed and Liquid Nitrogen Quenched Sandwich Panel Shown After Rough Trimming. The Panel Faces were X7106 and the Brazing Alloy was .005" Thick No. 719 Foil.

Consequently, the second panel incorporated assembly changes and the brazing temperature was decreased. The assembly changes were: 1) the panel faces were made smaller to keep them 2" away from the retort edge frames, and 2) stainless steel buffer sheets were increased to 0.1" thick to more 'fully pack' the retort. The brazing time cycle was shortened to 50 minutes by preheating the furnace to 1200°F and the brazing temperature was reduced to the range 1035° to 1050°F. Quenching was done as described for the first panel. Upon opening the retort, it was found that the brazing alloy had not fully melted. The retort then was resealed and the panel rebrazed through a cycle identical to that for Panel No. 1; i.e., 1050° to 1070°F. The second panel, after rebraze, is shown in Figure 43. Visual examination indicated that it was fully brazed and had uniform filleting throughout. Its shape was maintained very well through the brazing and quenching process. Element lines were straight and the curvature was uniform.

Both panels 1 and 2 were aged 48 hrs. at 250°F and were inspected as described below. Panel No. 1 edge trim material (braze coated) and panel extension material (not braze coated), were tensile tested at room temperature. The tensile data are reported below:

X7106 facings, 0.062" thick, cylindrical section brazement No. 1, liquid nitrogen quenched from 900°F and aged 48 hrs. at 250°F.

Specimen Number	Tensile Strength psi	Yield Strength psi	Elongation %
1	47,100	44,100	1.0
2	47,600	42,400	4.5
3	50,000	41,900	4.5
4	50,500	44,500	4.5
5	47,900	43,000	3.0

<u>Panel Extension</u> (same as above except not braze coated).

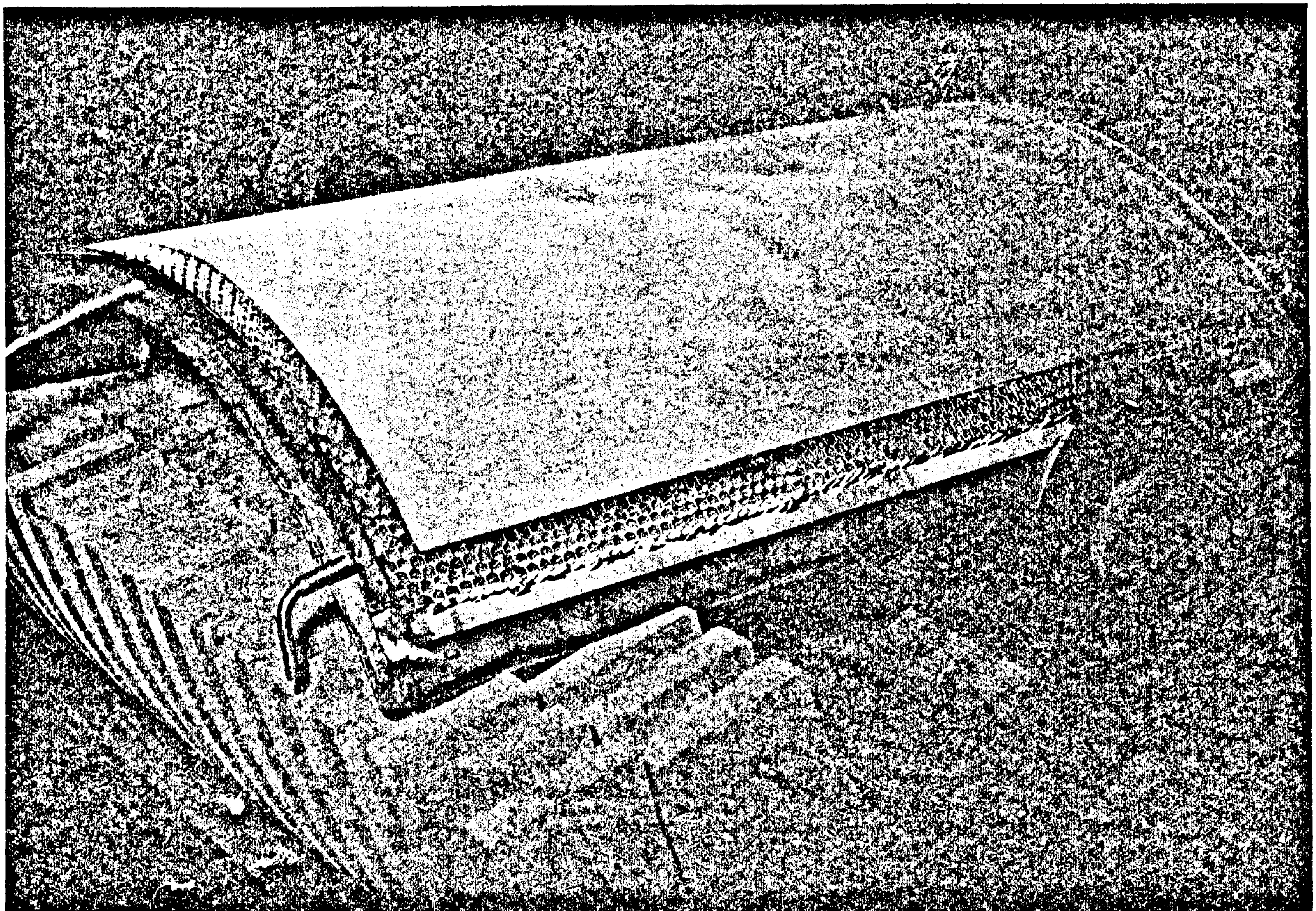


Figure 43 Second Brazed and Liquid Nitrogen Quenched Sandwich Panel Shown in Retort. The Panel Faces were X7106 and the Brazing Alloy was .005" Thick No. 719 Foil.

Specimen Number	Tensile Strength psi	Yield Strength psi	Elongation %
1	56,300	39,600	17.0
2	55,200	38,800	17.0
3	55,300	41,500	17.0
4	54,500	35,400	20.0
5	54,600	40,500	17.0

The panel extension data suggest that the described quenching rate still was not fast enough because the X7106 minimums were not achieved. The differences between data from panel extensions and from panel faces show the effect of the No. 719 brazing alloy on X7106. Ultimate tensile strength and elongation were reduced, but the yield strength was increased, as a result of brazing alloy diffusion.

Faster quenching can be achieved by post braze heat treating the panels without retorts. Previously, it was reported that liquid nitrogen quenched X7106 sandwiches had the following facing tensile properties:

F_{tu}	58,000 psi
F_{ty}	48,000 psi
Elong.	13%

Additional panel extension material, processed with cylindrical section brazement No. 1, was aged 72 hrs. at 250°F. It had the following tensile data:

Specimen Number	Tensile Strength psi	Yield Strength psi	Elongation %
1	58,000	48,700	10.5
2	55,400	46,100	12.5
3	55,100	46,800	10.0
4	56,000	47,200	8.5
5	56,800	47,600	11.5

Extended aging times significantly increased the yield strength of X7106--for the specific quenching rate reported on the preceding page.

2.2.3 Non Destruction Inspection Methods

Ultrasonic Inspection

The two cylindrical section brazements are subsequently identified as panel D and panel E. Panel D was the first one brazed. Panel E was the second brazement, which was processed through the double brazing cycle.

The ultrasonic inspection set-up for panels D and E is shown in Figure 44. Both the panel and transducer were submerged in water for the inspection. The signal from the transducer was automatically printed to provide a permanent record of the inspection. Photographs of the inspection records and the panels are shown in Figures 45 through 48 . Figure 49 shows the result of a repeat inspection of the central portion of the concave side of panel E.

The ultrasonic inspection records showed the panels to be at least 90% brazed. Most of the evident voids were attributed to discontinuities in the brazing alloy foil or honeycomb core assembly.

Radiographic Inspection

A series of tests were conducted using a beryllium filter X-ray tube in contrast to a nonfiltered X-ray radiation used elsewhere in this report. Time, voltage and film type were varied to determine optimum inspection parameters.

Figures 50 and 51 show optimum ranges of operating parameters and positive prints of typical radiographs. Figure 51 shows a portion of the radiograph of curved panel D.

A detailed comparison of radiographic and ultrasonic inspection confirmed that the ultrasonic inspection report was accurate and destructive inspection of edge trim material further substantiated the accuracy of the ultrasonic inspection report.

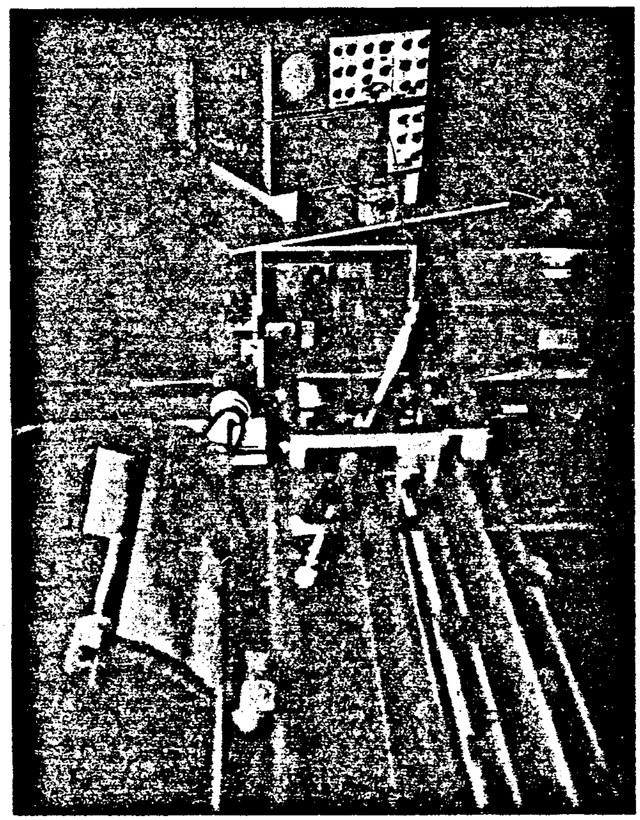


Figure 44 Set-up for Ultrasonic Inspection of Curved Brazement. Photograph and Service Provided by Automation Industries, Inc., Columbus, Ohio.

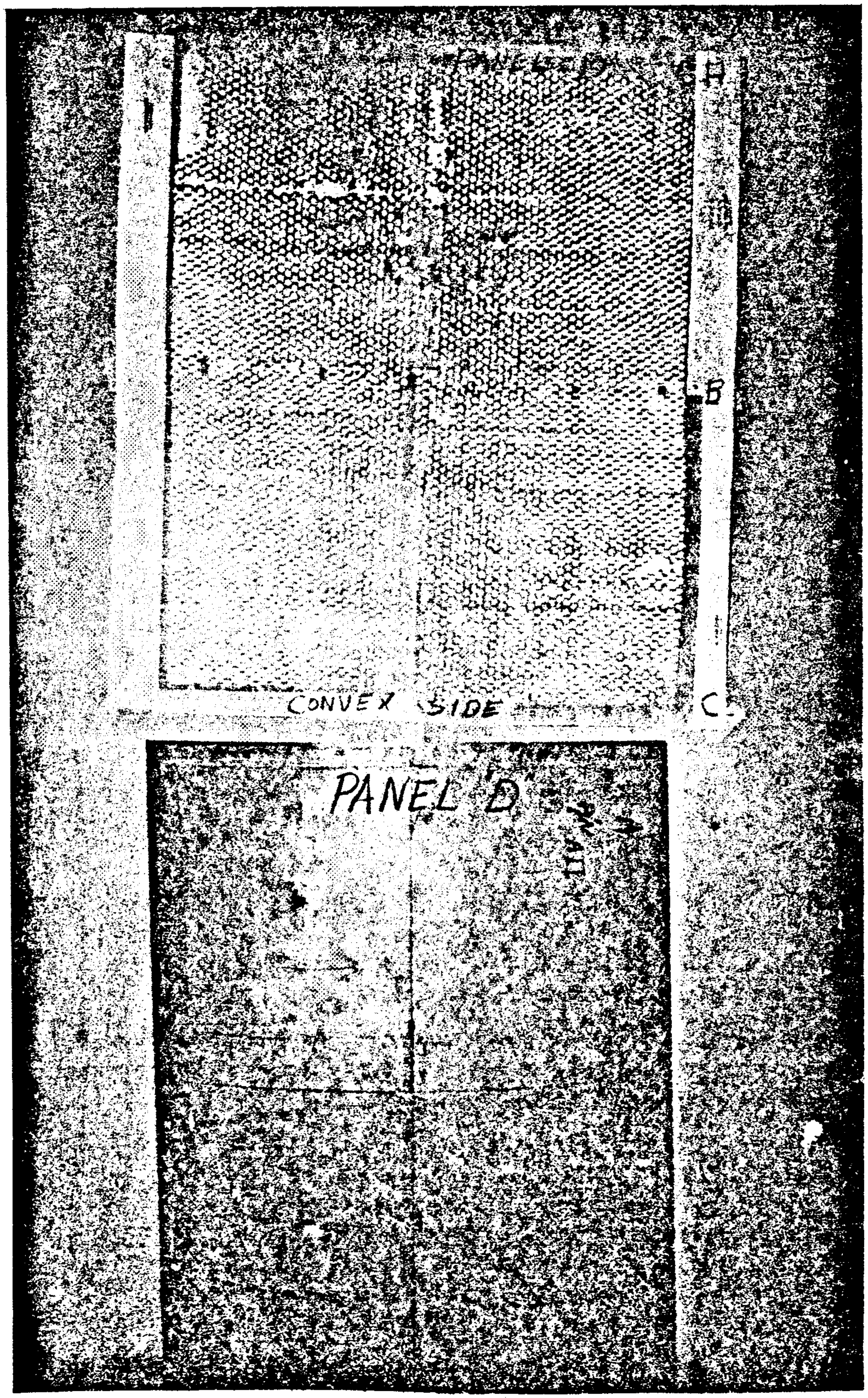


Figure 45 Convex Side of Brazed Honeycomb Sandwich Panel D and its Corresponding Ultrasonic Inspection Record.

NOT REPRODUCIBLE

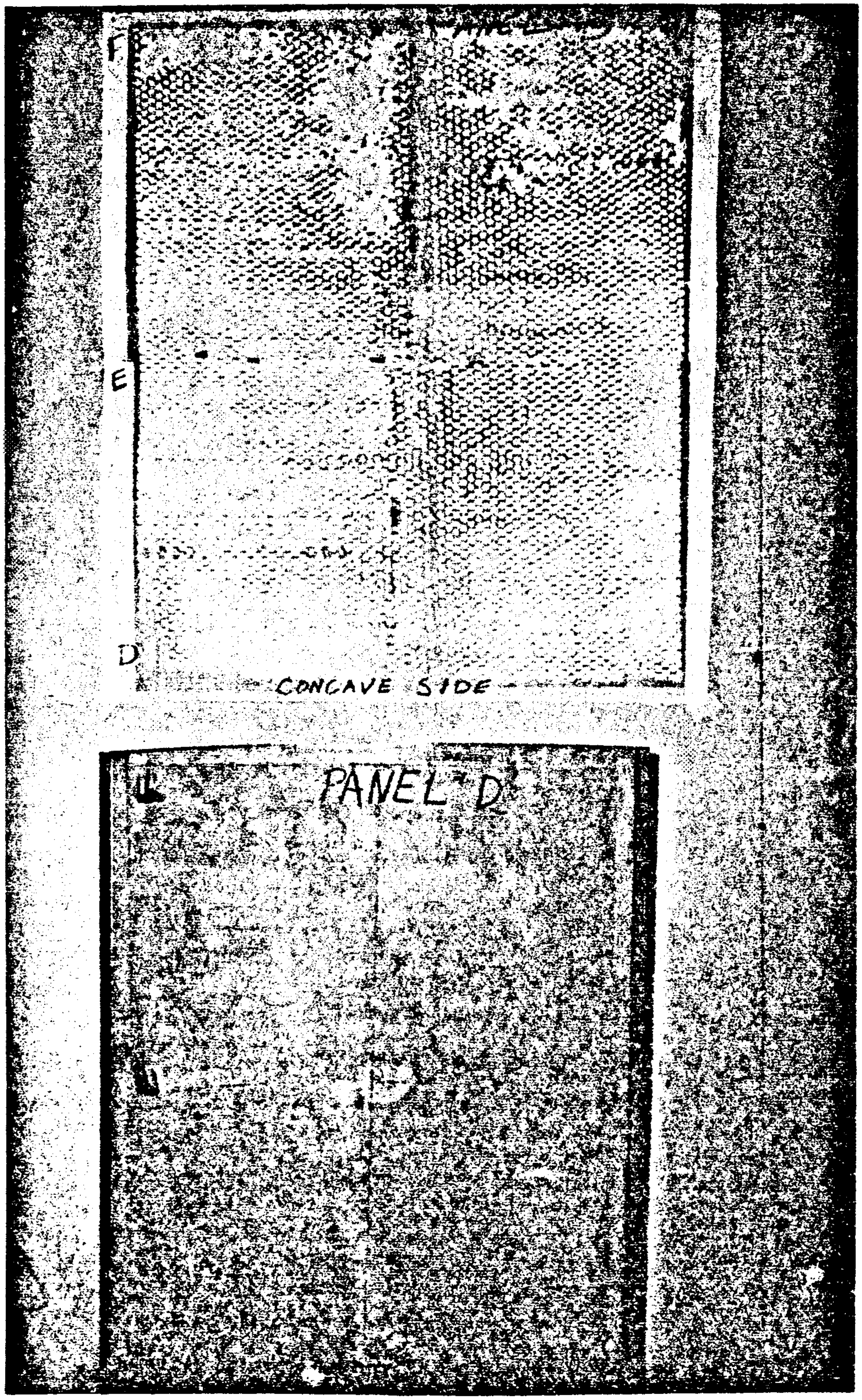


Figure 46 - Concave Side of Brazed Honeycomb Sandwich Panel D and Its Corresponding Ultrasonic Inspection Record.

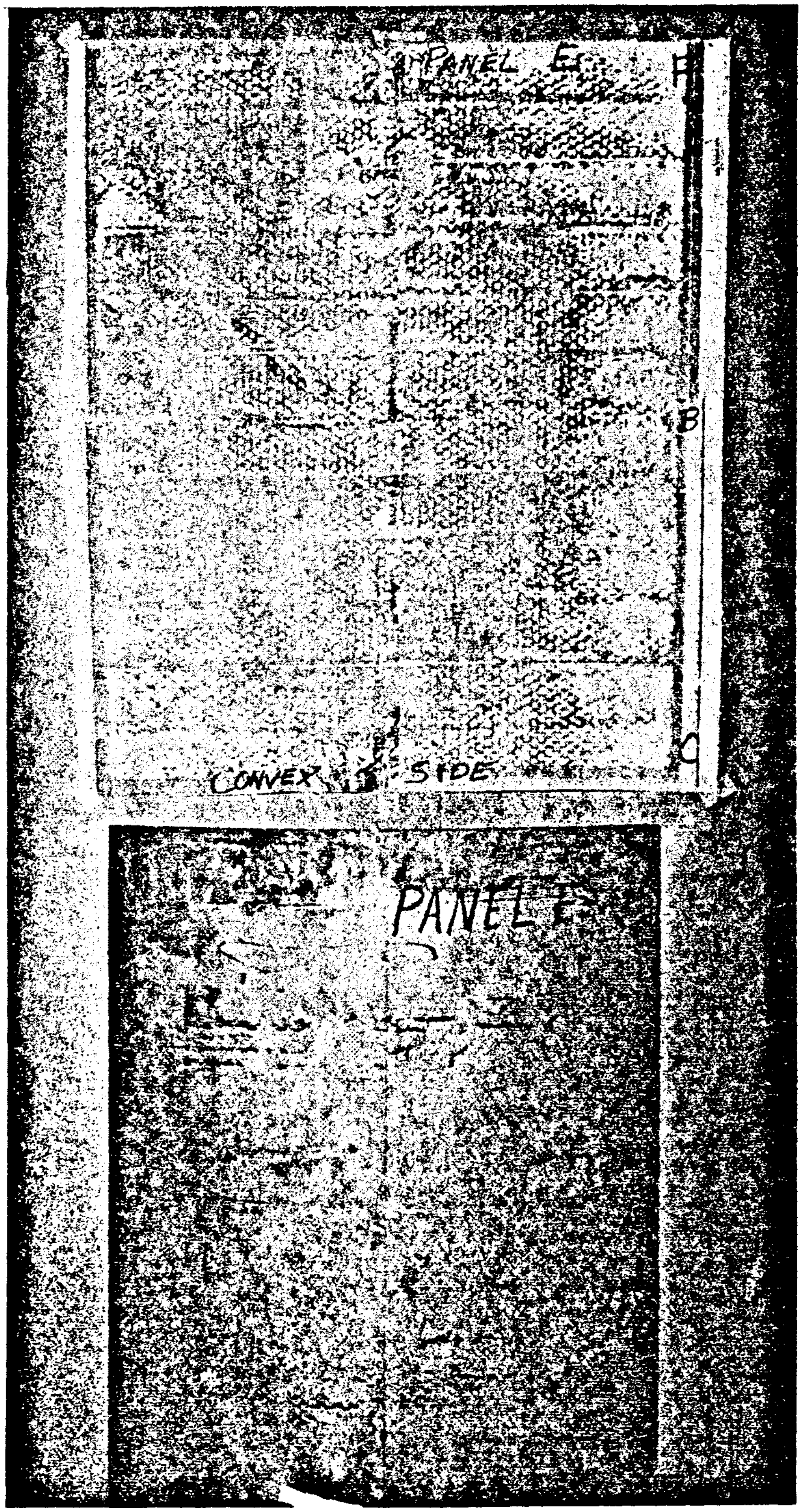


Figure 47 Convex Side of Brazed Honeycomb Sandwich Panel E and its Corresponding Ultrasonic Inspection Record.

NOT REPRODUCIBLE

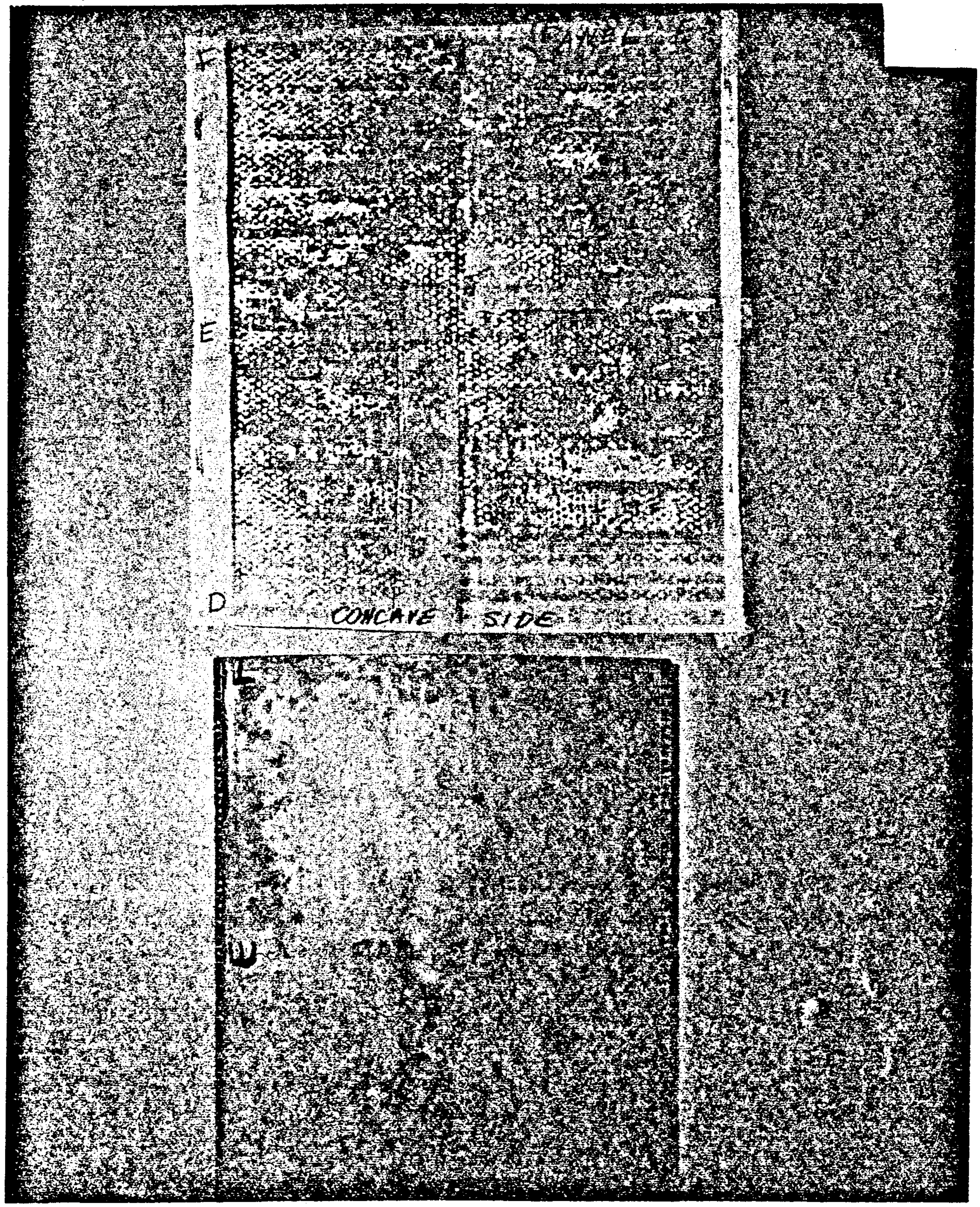


Figure 48 Concave Side of Brazed Honeycomb Sandwich Panel E and its Corresponding Ultrasonic Inspection Record.

NOT REPRODUCIBLE

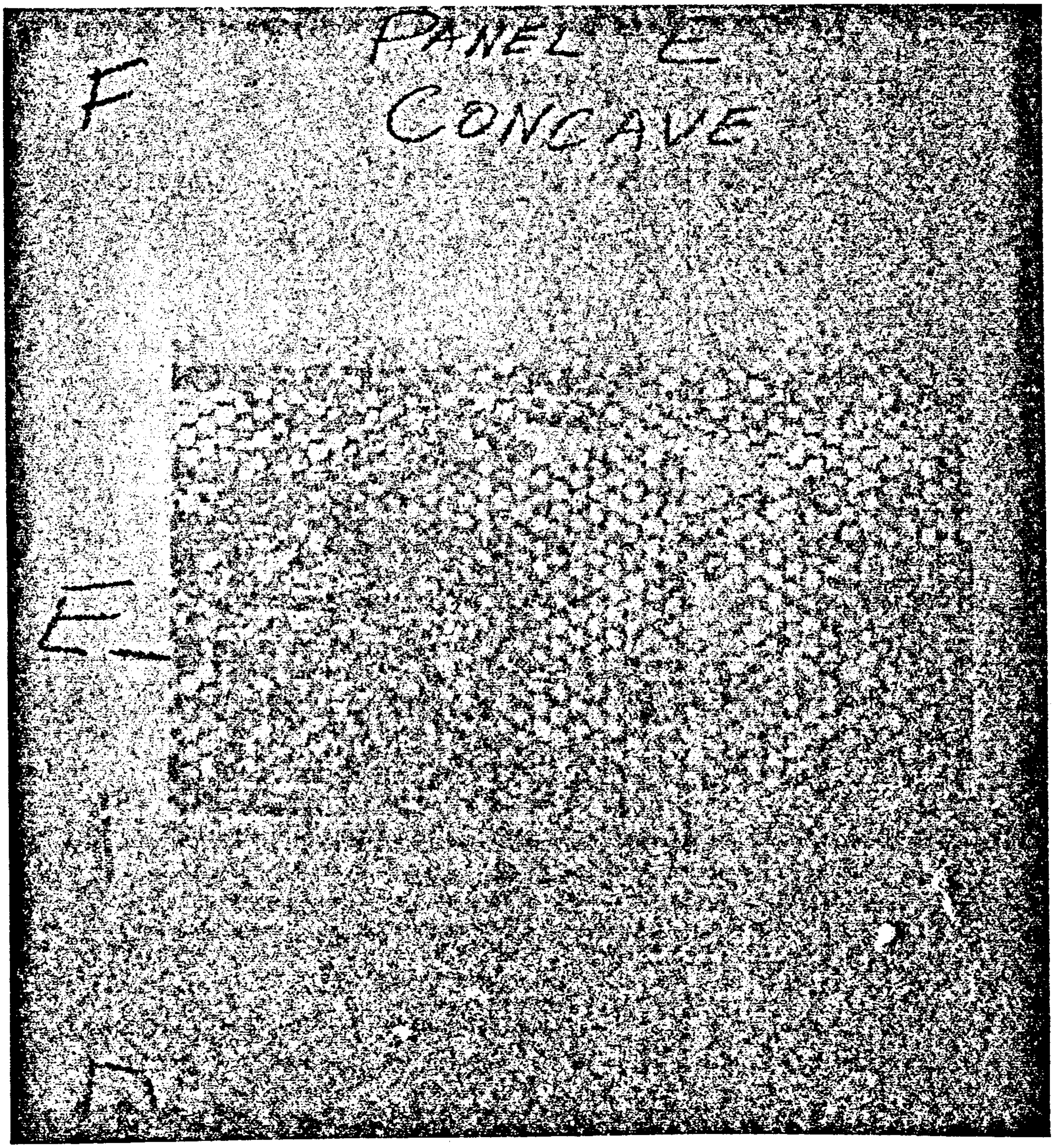


Figure 49 **Ultrasonic Inspection Record of an Inspection Rerun of the Central Portion of the Concave Side of Brazed Honeycomb Sandwich Panel E.**

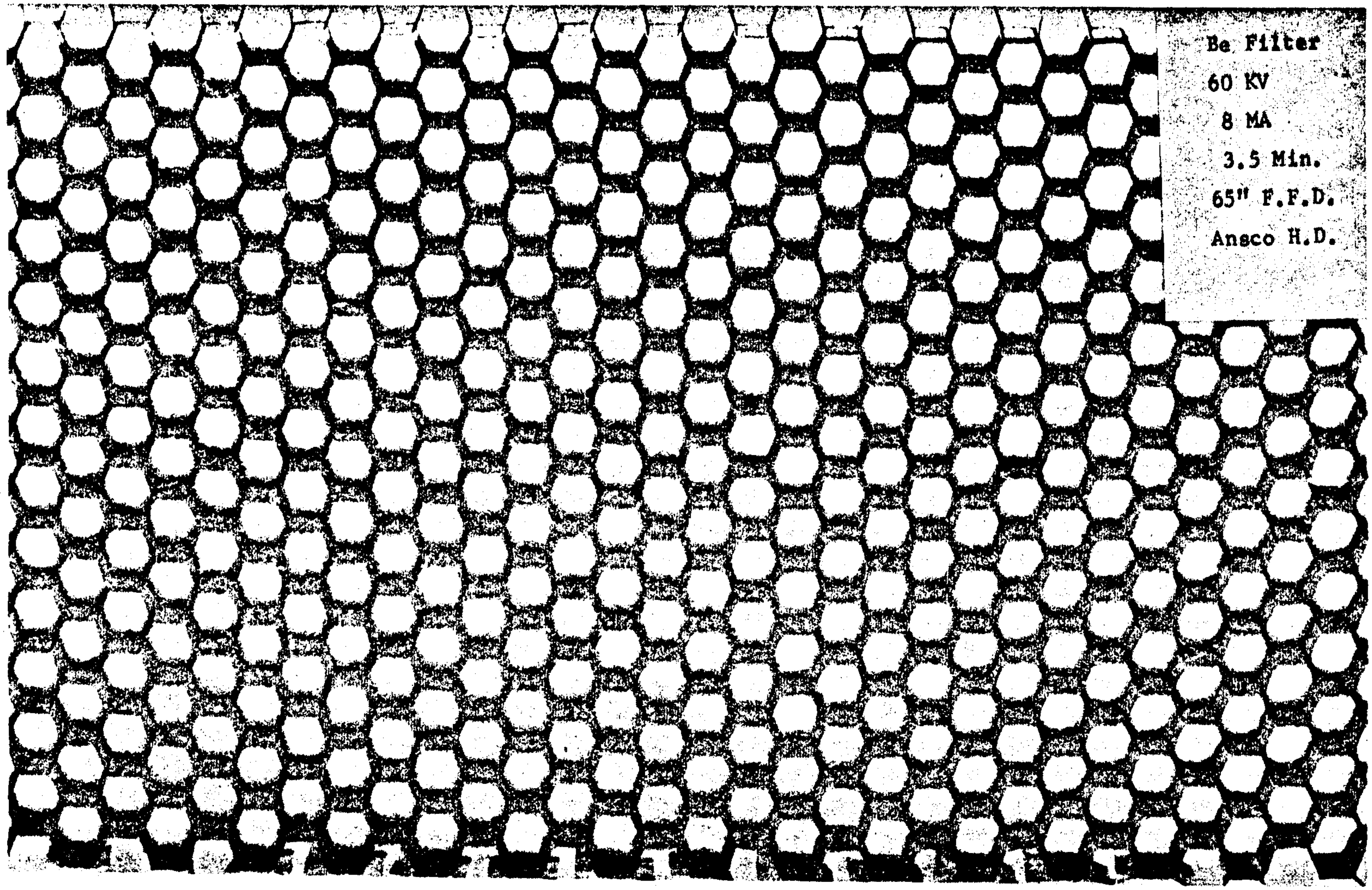


Figure 50 Positive Print of the Radiograph of Flat Sandwich Panel No. 11, Using Beryllium Filtered X-ray Radiation. Compare with Figure 61, Summary Annual Report, NAS8-5445, which Describes the Panel and Shows an Identical Radiograph made with Nonfilter X-ray Radiation.

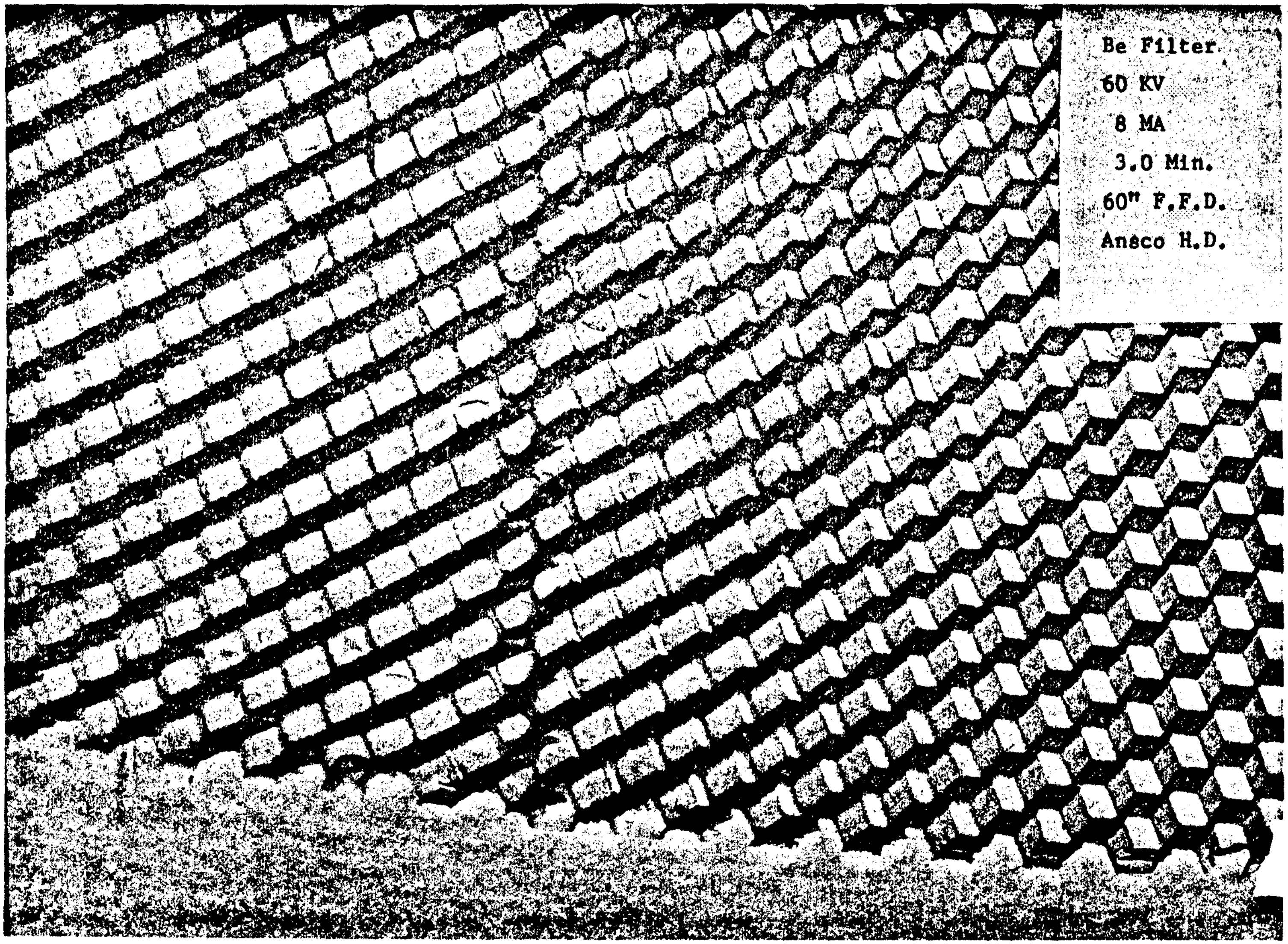
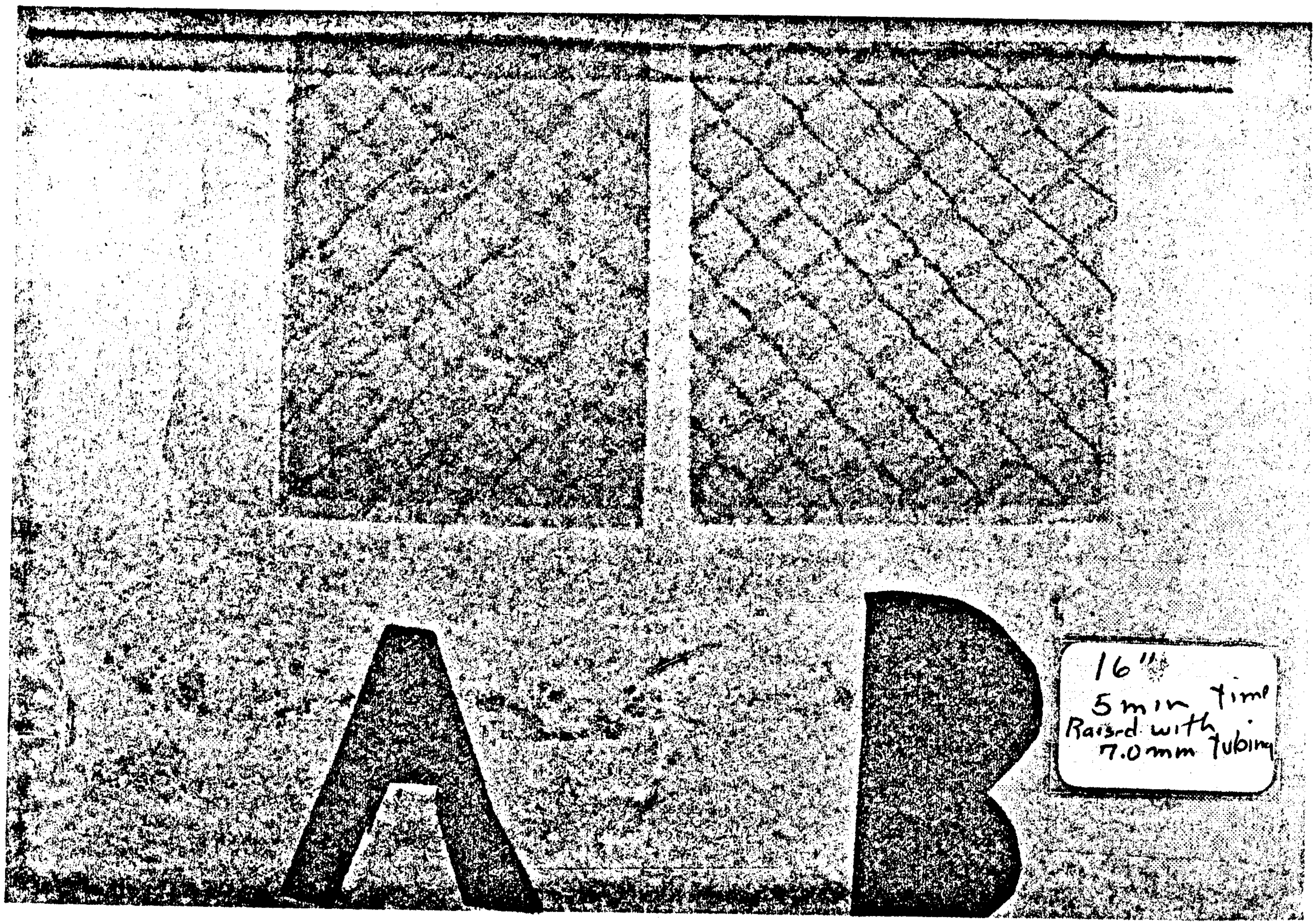


Figure 51 - Positive Print of a Portion of the Radiograph of Curved Sandwich Panel D, using Beryllium Filtered X-ray Radiation.



ßx Figure 52 Radiographs of Brazed Aluminum Panels provided by Oak Ridge National Laboratory. Film: Polaroid 3800X. Source: 225 Curie $^{147}\mathrm{Pm}$ 7 mm dia., covered with 15 Mil dia. window.

A - Panel No. 5: B - Panel No. 1

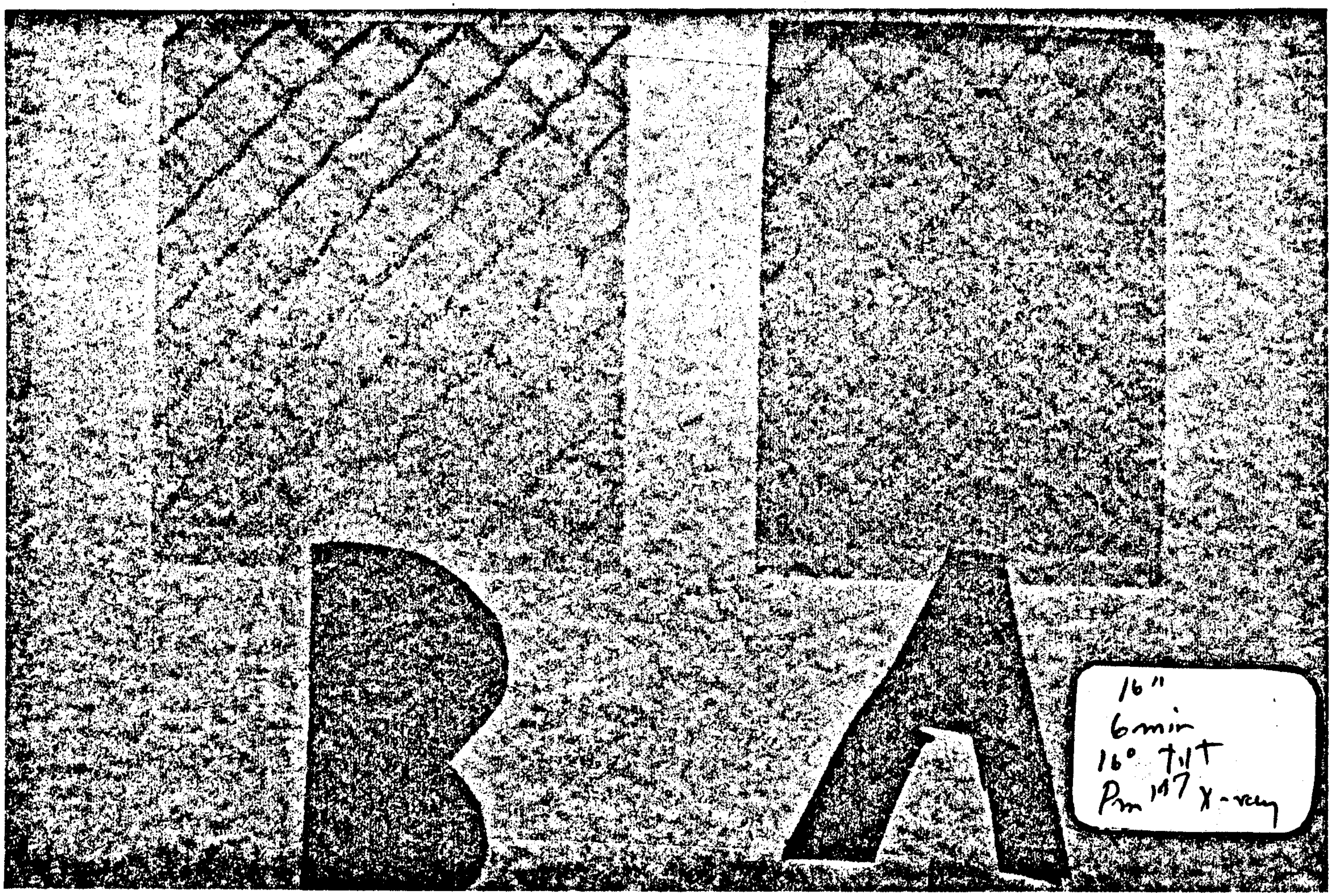


Figure 53 Radiographs of Brazed Aluminum Panels provided by Oak Ridge National Laboratory. Film: Polaroid 3800X. Source: 225 Curie $_{Pm}147$ 7 mm dia., Covered with 15 Mil dia. window.

A - Panel No. 5 B - Panel No. 1

Comparing panels D and E and their inspection reports with similar reports on panels A through GG (Section 2.1), the non-destructive techniques are only useful to define large, distinctive fillets, or areas of complete void. Questionable brazes would require proof testing or an experimental program to develop standards which compare proof loads and inspection reports; ideally, such a program would be done with identical materials and material gauges that were used in some specific hardware.

Two additional inspection methods were evaluated and are reported below:

Isotope Radiography

Samples were sent to the Isotopes Dev. Center* for radiography with the isotope Pm^{147}. The procedure and results are shown in Figures 52 and 53

The conclusion was that conventional X-ray procedures produced more definitive information.

Thermography

The Magnaflux Corporation offers an inspection system trade-named 'Bondcheck'. It is most useful for sandwiches having facing thickness of 0.025" or less. Its use was attempted on an 0.040" facing thickness aluminum sandwich without success. A specimen of brazed aluminum sandwich then was sent to the Magnaflux Corporation for their analysis.

Magnaflux reported the following:

> "Attempts to indicate the unbonded areas in the submitted sample using BC-2, 3 and 4 were unsuccessful. The skin surface was heated to approximately 400°F without any pattern indications being formed. We were able, however, to develop pattern indications using BC-1

*Courtesy of F. N. Case, Isotopes Dev. Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

test fluid. Unfortunately, the indications are fugitive; they do, however, remain long enough to enable the viewer to distinguish between the bonded and unbonded areas. The pattern indications began to form at approximately 160°F, the maximum temperature attained was 200°F. This is well within Aeronca's tolerances (250°F to 375°F)."

2.3 BRAZED AND LIQUID NITROGEN QUENCHED FLAT PANELS

This section presents the brazing and testing results for honeycomb core sandwich panels fabricated from X7005 and X7106. They differ from the panels described in Section 2.1 in several import aspects: 1) the honeycomb core was fabricated from 0.005" thick foil, rather than 0.008" foil, and had a resulting core density of 6.2 lbs. per cubic foot; 2) the brazing alloy was 0.005" thick foil, rather than preplaced, flame sprayed brazing alloy coatings; an 3) rapid quenching rates were accomplished by quenching the panels into liquid nitrogen.

Four panels, each five square feet in size, were to be brazed to provide a sufficient number of test specimens for the testing program. Two panels had X7005 faces and core and two panels had X7106 faces and X7005 core. The No. 719 brazing alloy was used in the form of 0.005" thick foil in all panels.

Twenty square feet of honeycomb core were fabricated by resistance welding and machined flat by sanding. The X7005 core was a nominal Type 6-50 x 1/2", hexagonal cell. The 0.005" thick X7005 ribbon was resistanced welded without problems. The measured core density was 6.2 pounds per cubic foot. Precise measurements of the completed core, as used in subsequent calculations, were the following:

Blanket Thickness	0.52"
Ribbon Thickness	0.0054"
Cell Size, diagonal to node welds	0.353"
Cell Size, normal to node welds	0.367"

In keeping with past part identification procedure, the panels were given consecutive letter identifications. The first panel with X7005 faces was identified "F", the second panel with X7005 faces was identified "FF". Similarly, the two panels with X7106 faces were identified "G" and "GG".

The order in which the panels were brazed was important with respect to tooling methods, brazing cycle, and subsequent material properties; accordingly, the brazing order and panel description appear in Table 25.

2.3.1 Tooling and Brazing Methods

Stainless steel was selected for the retort material, for the first two brazements (panels F and G). The third and fourth brazements were brazed in aluminum retorts, fabricated from alloy 3003.

The panels were 24" x 30" in size and the retorts were approximately 6" larger, having 0.060" thick u-channel edge members and 0.030" thick faces. One thermocouple was centrally located in each of the four retort edge members. The thermocouples were welded to the closed-end tubes on the stainless steel retorts, but were crimped in place in the aluminum tubes of the aluminum retorts.

Brazing was done in a large, bottom-drop, circulating air furnace, which had been shown in Section2.2.The first brazement (F) was made without external fixturing and the stainless steel retort warped during cool-down from the brazing temperature. The second retort (G) was positioned in the fixture described in Figure 54. It also warped during cool-down, but the warpage was less severe than the first. The next two brazements (FF and GG) were made in aluminum retorts positioned in the brazing fixture as shown in Figure 55. Note, however, that the mass of the fixture was reduced by cutting down each half from the original thickness of 12" to 6". No warpage occurred with the aluminum retorts and panels FF and GG were flat within the limits of the fixture.

Brazing Parameters and Results

The aluminum alloy panel parts and retort parts were cleaned with a mild abrasive cleaner and hot vapor degreased. In addition, the brazing alloy foil and panel faying surfaces were hand sanded and degreased a second time.

TABLE 25

PANELS BRAZED AND BRAZING ORDER

Panel Code	Panel Description	Brazing Order	Brazing Tooling Method
F	62 Mil X7005 Facings Type 6-50 X7005 Core 719 Brazing Alloy 5 Mils thick per face for all panels	1	Stainless Steel Retort No Fixture
G	62 Mil X7106 Facings Type 6-50 X7005 Core	2	Stainless Steel Retort with External Fixture
FF	62 Mil X7005 Facings Type 6-50 X7005 Core	3	Aluminum Retort with External Fixture
GG	62 Mil X7106 Facings Type 6-50 X7005 Core	4	Aluminum Retort with External Fixture

Note: All panels were furnace brazed in the range of 1045° - 1075°F. All panels were 24"x30"x0.64" thick.

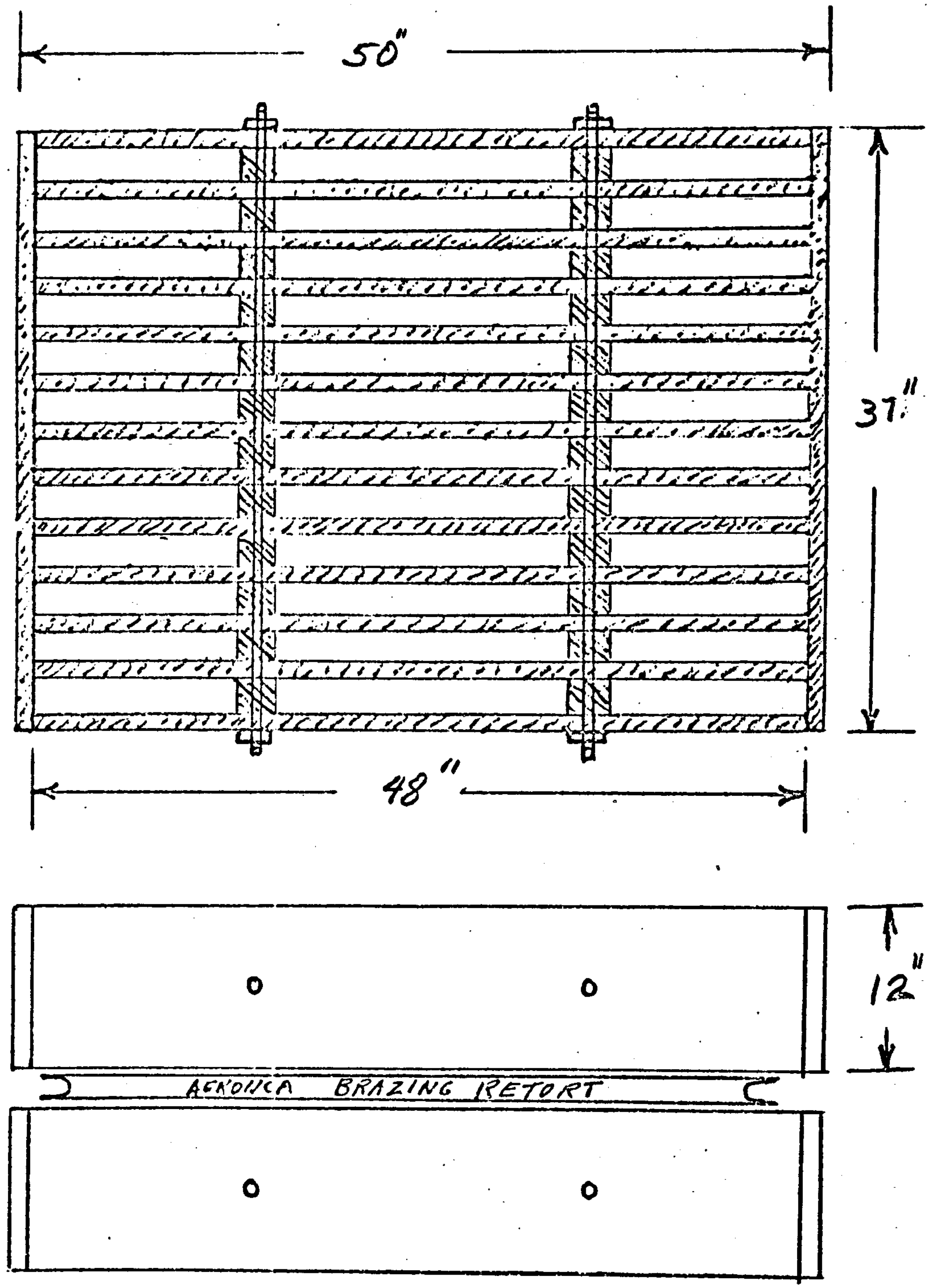


Figure 54 - Flat Brazing Fixture Fabricated from 1" Thick Asbestos Cement Board

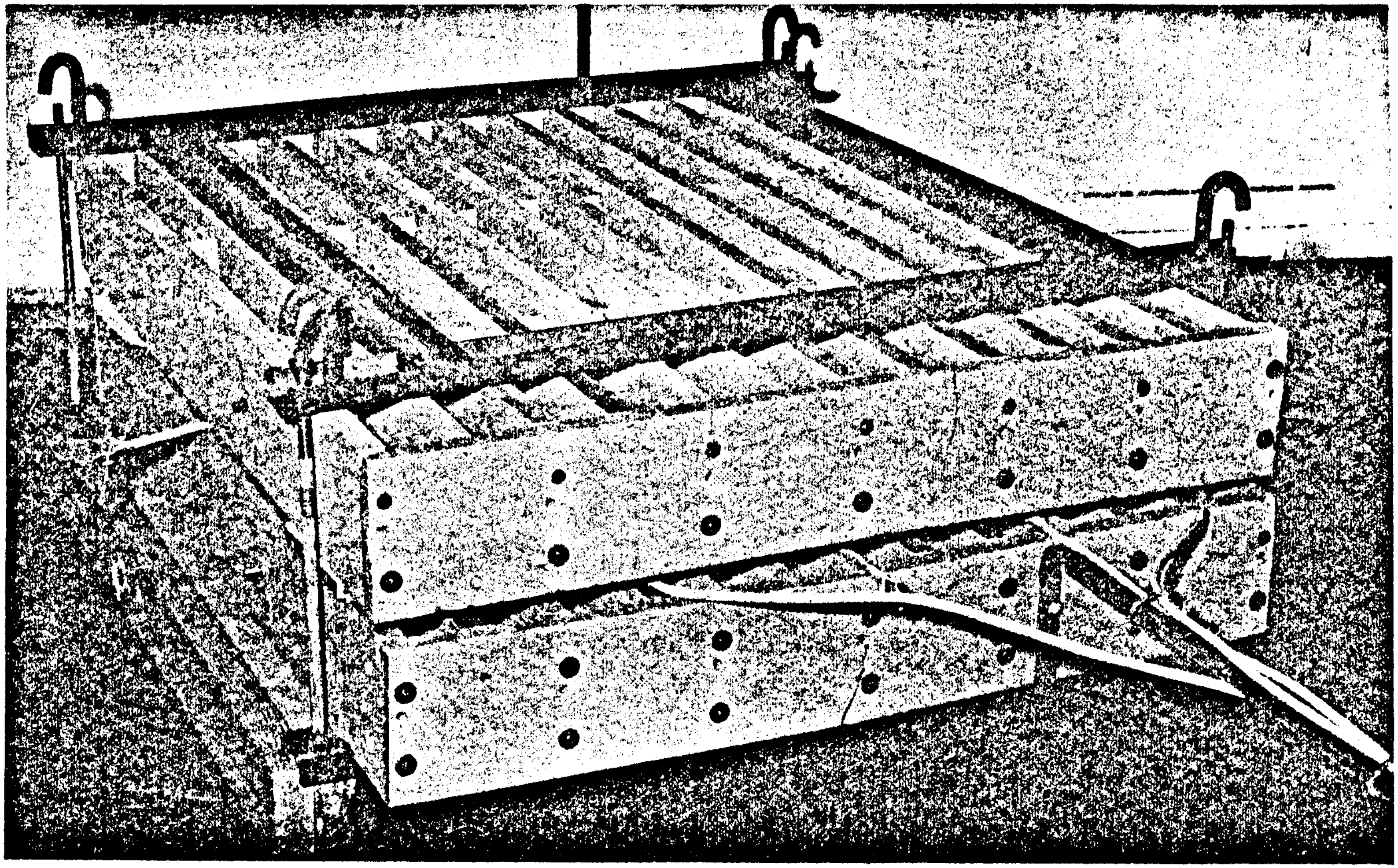


Figure 55 - Fixturing setup for Brazing Panels FF and GG.

After panel was retort assembly was completed, the retorts were leak checked by evacuation, then purged five times with purified argon. The argon flow rate was set at 15 CFH for the brazing cycle with the retort slightly evacuated to provide an atmospheric clamping pressure of 0.1 psi.

Brazing time-temperature cycles are shown in Figure 56. Panel F, without external fixturing, had the fastest total time cycle. Panel G, with the most massive fixture had the slowest total time cycle. Panel FF was purposely brazed at a slightly lower time-temperature cycle than F, because examination of Panel F showed a substantial amount of brazing alloy run-down with large bottom face fillets and small top face fillets. During the FF brazing cycle at approximately 950°F, the aluminum vacuum tube separated from the retort; consequently there was no face-to-core clamping pressure and atmospheric contamination may have back-streamed into the retort. Panel GG was brazed at an intermediate time-temperature cycle. The brazing time-temperature cycles and results are summarized in Table 26.

Radiographic examination showed that panels G and GG were 100% brazed and had uniform fillets throughout, except that bottom-face fillets were slightly larger than top-face fillets.

Radiographs of Panel F showed that approximately 2/3 of the brazed panel was not acceptable. There were large areas without face-to-core contact and other areas with sheared core at the fillets; both apparently caused by warpage during cool-down. Radiographs of Panel FF showed incomplete melting of the brazing alloy, but most of the panel had small, well defined fillets.

There was no evidence of crushed or dissolved core in any of the four panels.

Figure 57 shows Panel F with its specimen layout and an example of a torn core is shown also in Figure 58. A portion of Panel FF is shown in Figure 59. Since the quality of Panel FF was not definitely established by radiography,

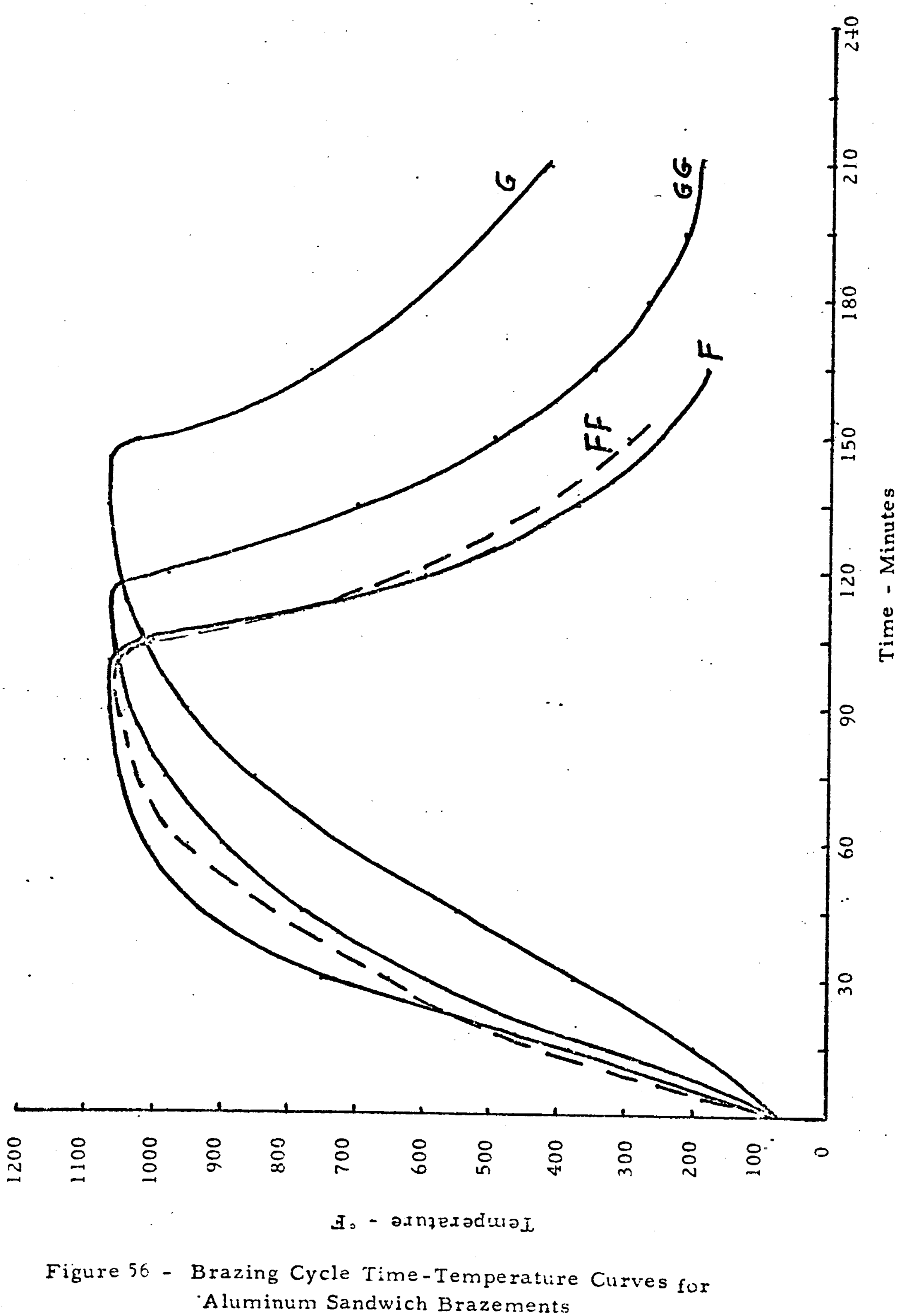


Figure 56 - Brazing Cycle Time-Temperature Curves for Aluminum Sandwich Brazements

TABLE 26

BRAZING TIMES AND RESULTS

Panel Code	Brazing Temperature	Time at Temperature	Braze Quality (percent of total area)	Remarks
F	1050° - 1065°F	10 minutes	30% brazed, owing to warpage	
FF	1045° - 1060°F	6 minutes	80% brazed, small fillets	
G	1050° - 1075°F	25 minutes	100% brazed, uniform filleting	
GG	1050° - 1070°F	10-12 minutes	100% brazed, uniform filleting	

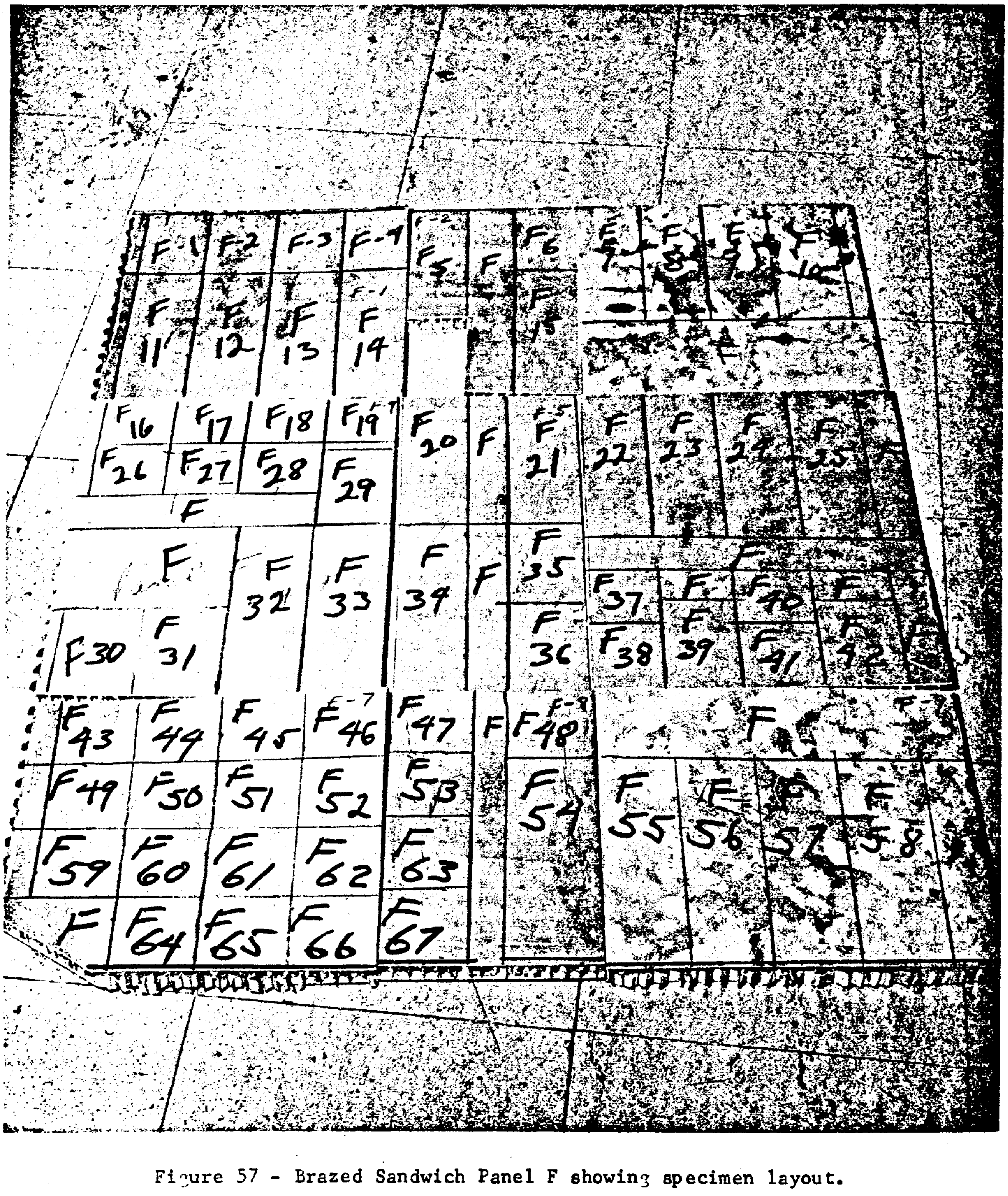


Figure 57 - Brazed Sandwich Panel F showing specimen layout.

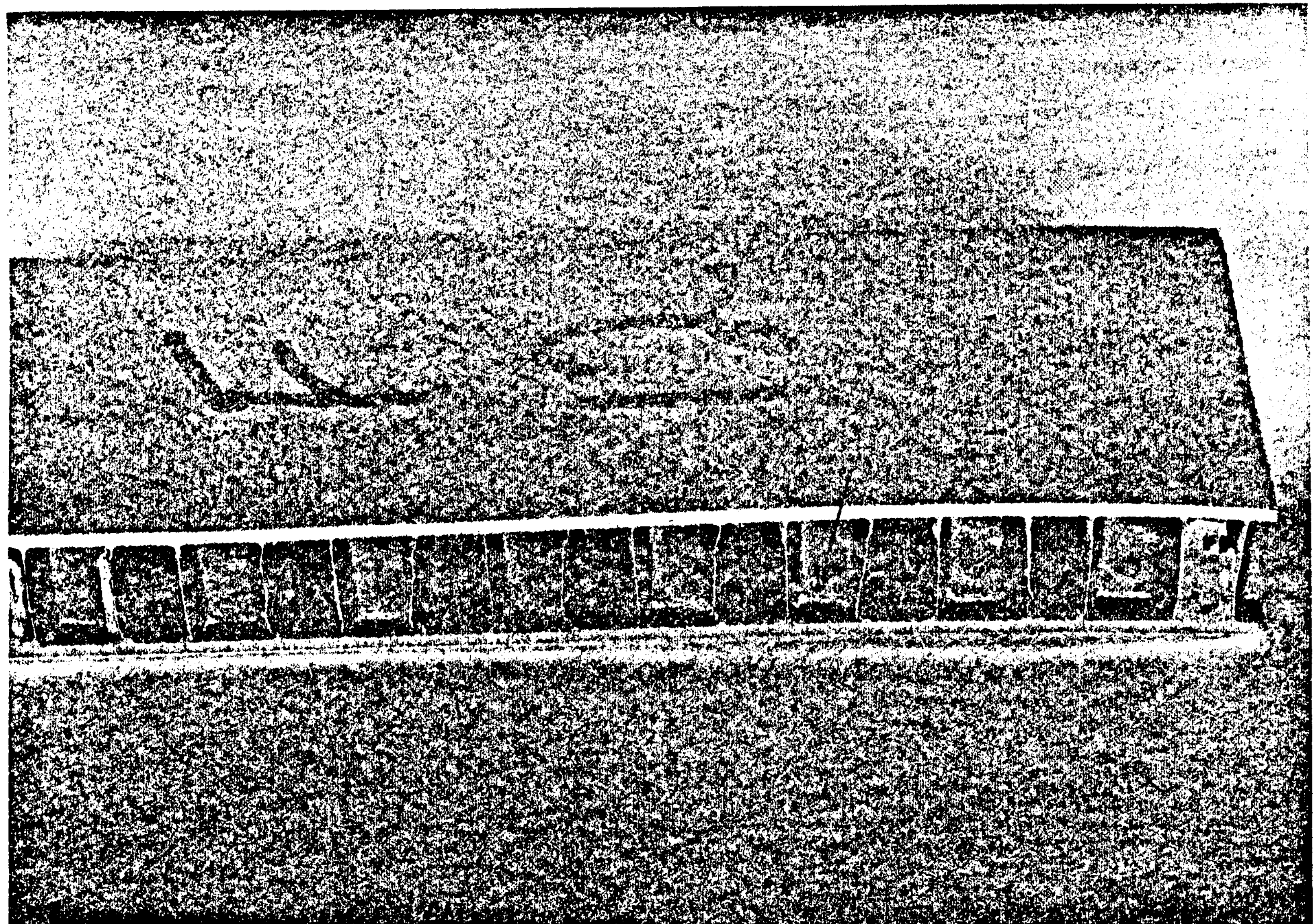


Figure 58 - Section of Panel F showing separation in the core-to-face joint.

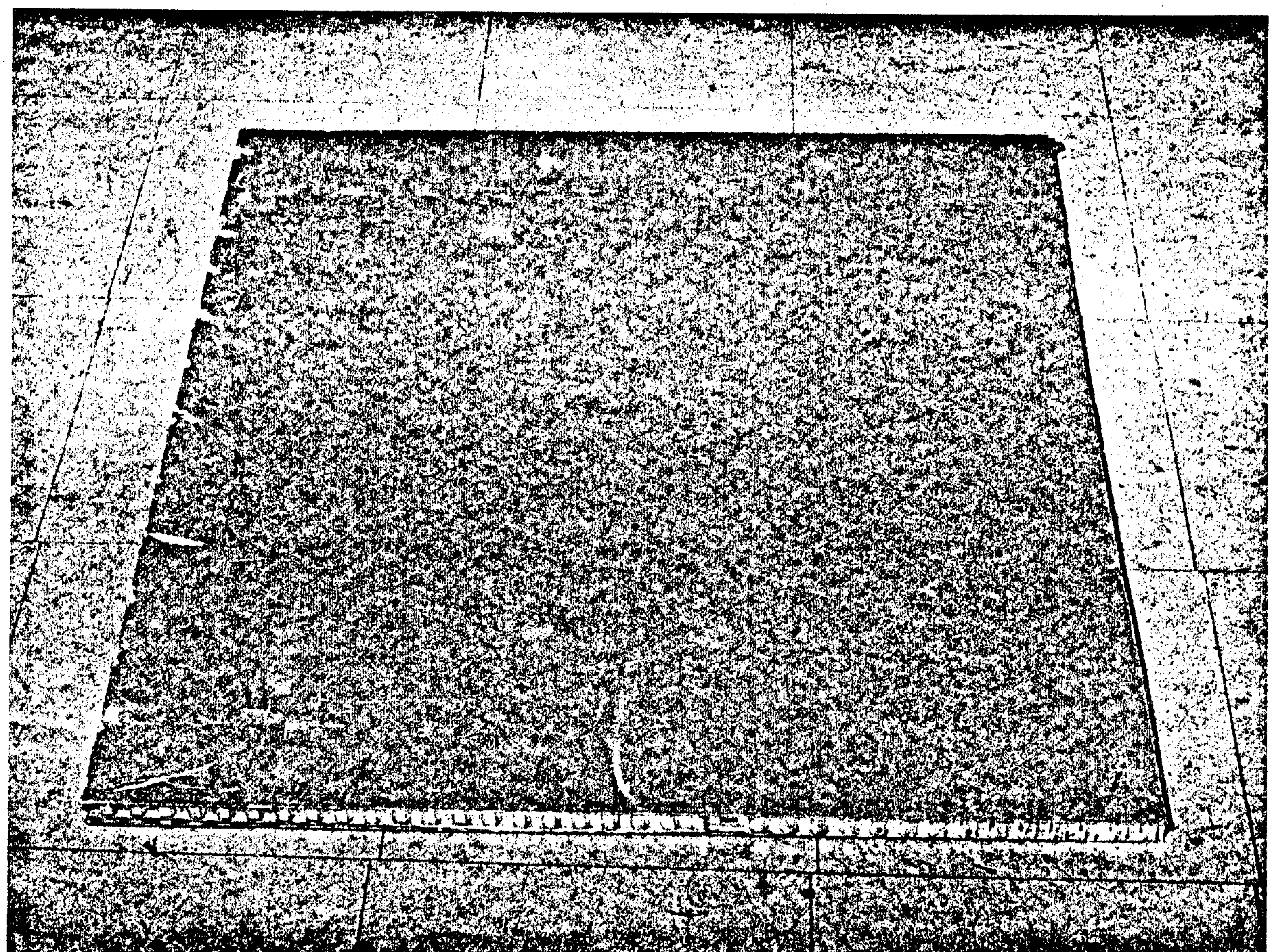


Figure 59 - A portion of brazed Panel FF.

a flatwise tensile test was conducted. The specimen failed at a low stress level because of incomplete brazing alloy melting as shown in Figure 60.

Macrographs of Panels F and FF (sectioned near node weld joint) are shown in Figure 61. Note that there was no appreciable diffusion of the No. 719 brazing alloy into the X7005 faces. Although the brazing alloy flowed on the core cell walls, there was no significant flow and filleting in the node joints.

Panels G and GG are shown in Figures 62 and 63 and their respective macrographs are shown in Figure 64. Brazing alloy diffusion into the X7106 faces occurred to depths ranging from 0.010" to 0.030". Panel G had a substantial amount of node flow, but Panel GG had node flow in only local areas.

Heat Treatments

Panels F and FF (X7005) were quenched by the brazing cycle and aged 7 days at room temperature and 96 hours at 250°F. The quenching rate was 15° to 20°F per minute.

Panels G and GG (X7106) were heat treated after brazing by solutioning for 30 minutes at 875°F followed by quenching into liquid nitrogen. The aging treatment was 1 day at room temperature and 96 hours at 250°F.

All of the specimens from Panels G and GG were tested and selected specimens from Panel F were tested. Panel FF was considered scrap, except for facing tensile coupons.

2.3.2 Test Program

Table 27 summarizes the room temperature test data and compares it with calculated values.

Figures 65 through 73 summarize all of the test results in graphical form and the detailed test data are presented in Tables 27 through 43. The results are discussed below with respect to the brazing process and to the sandwich properties.

Effect of Brazing Process on the Sandwich Facing Materials

Tensile data on the sandwich facing extensions (bare) show that the

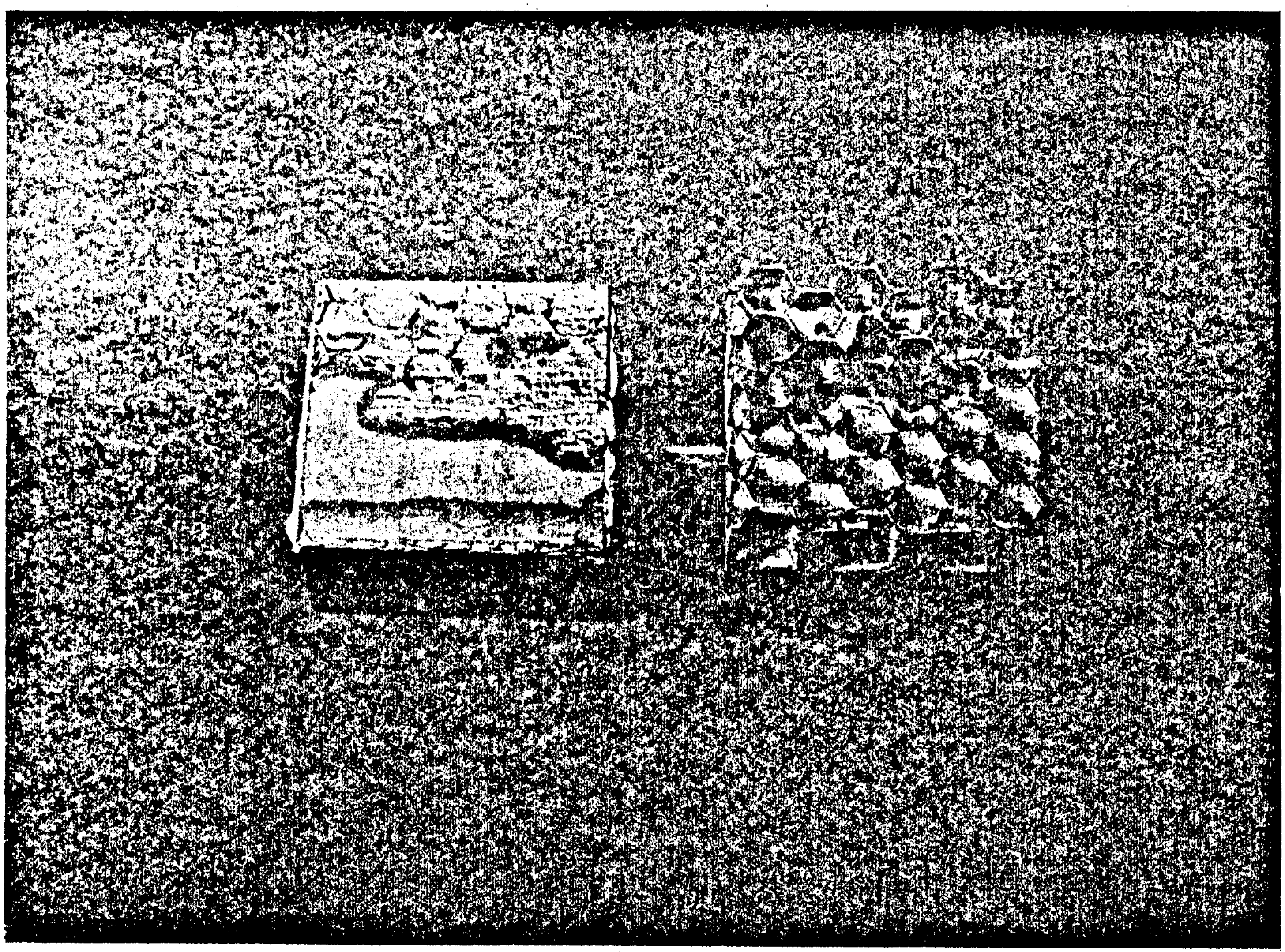


Figure 60 - A failed flatwise tensile specimen from Panel FF showing incomplete brazing alloy melting and lack of face-to-core contact.

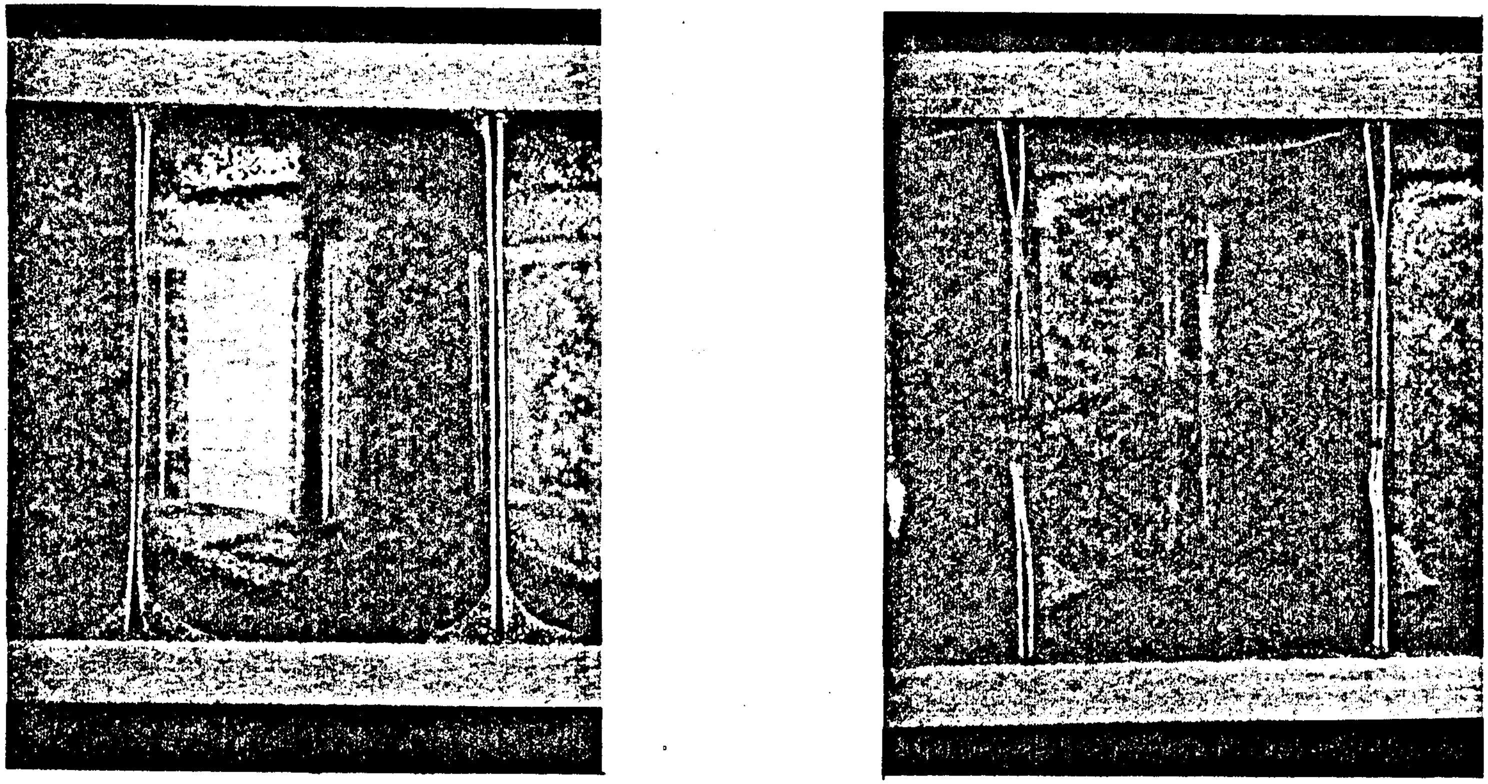


Figure 61 - Left: Section from Brazed Panel F showing large fillets on the lower side. Mag. 6X

Right: Section from Brazed Panel FF showing incomplete brazing alloy melting. Mag. 6X

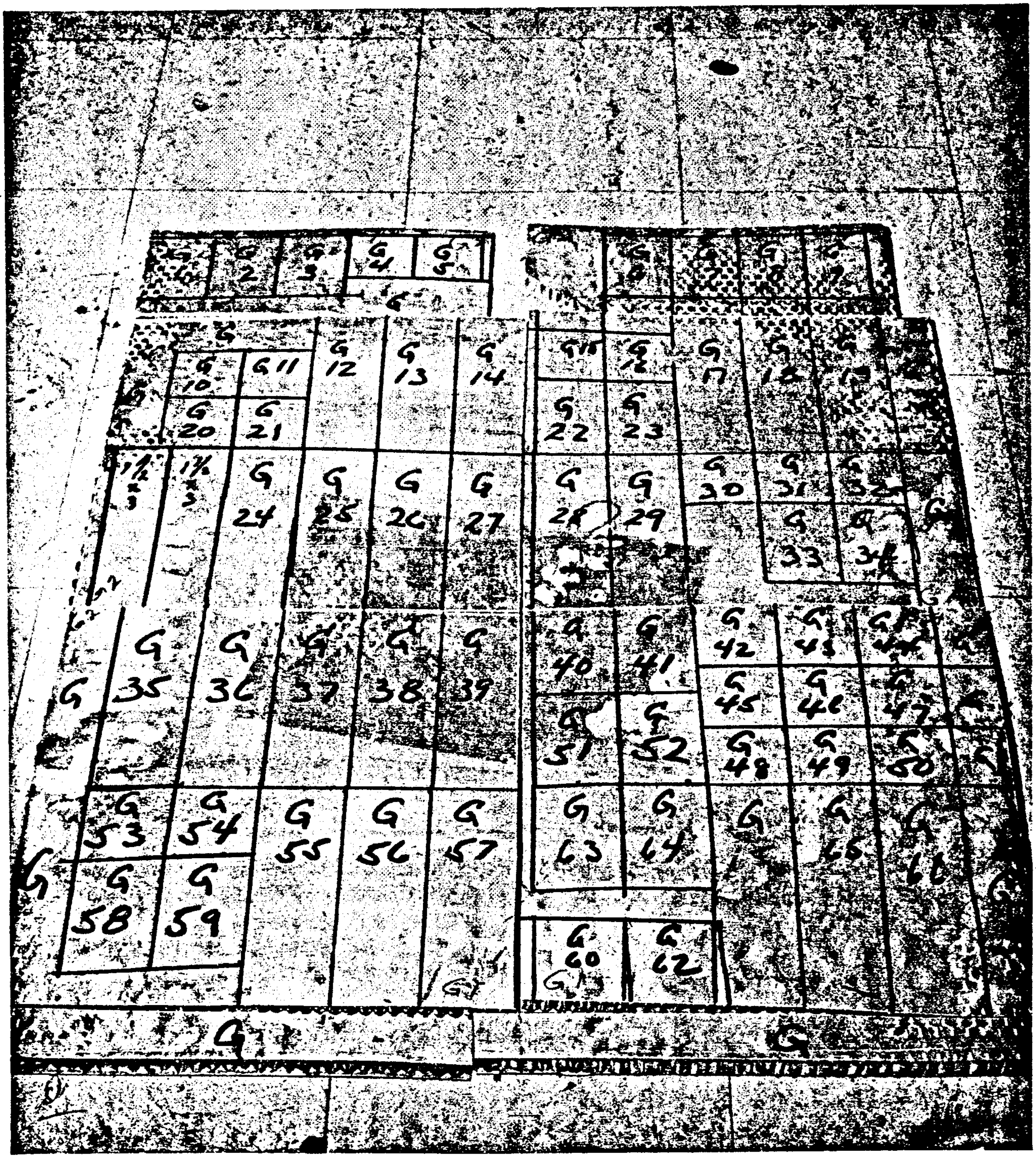


Figure 62 - Brazed Sandwich Panel G showing specimen layout.

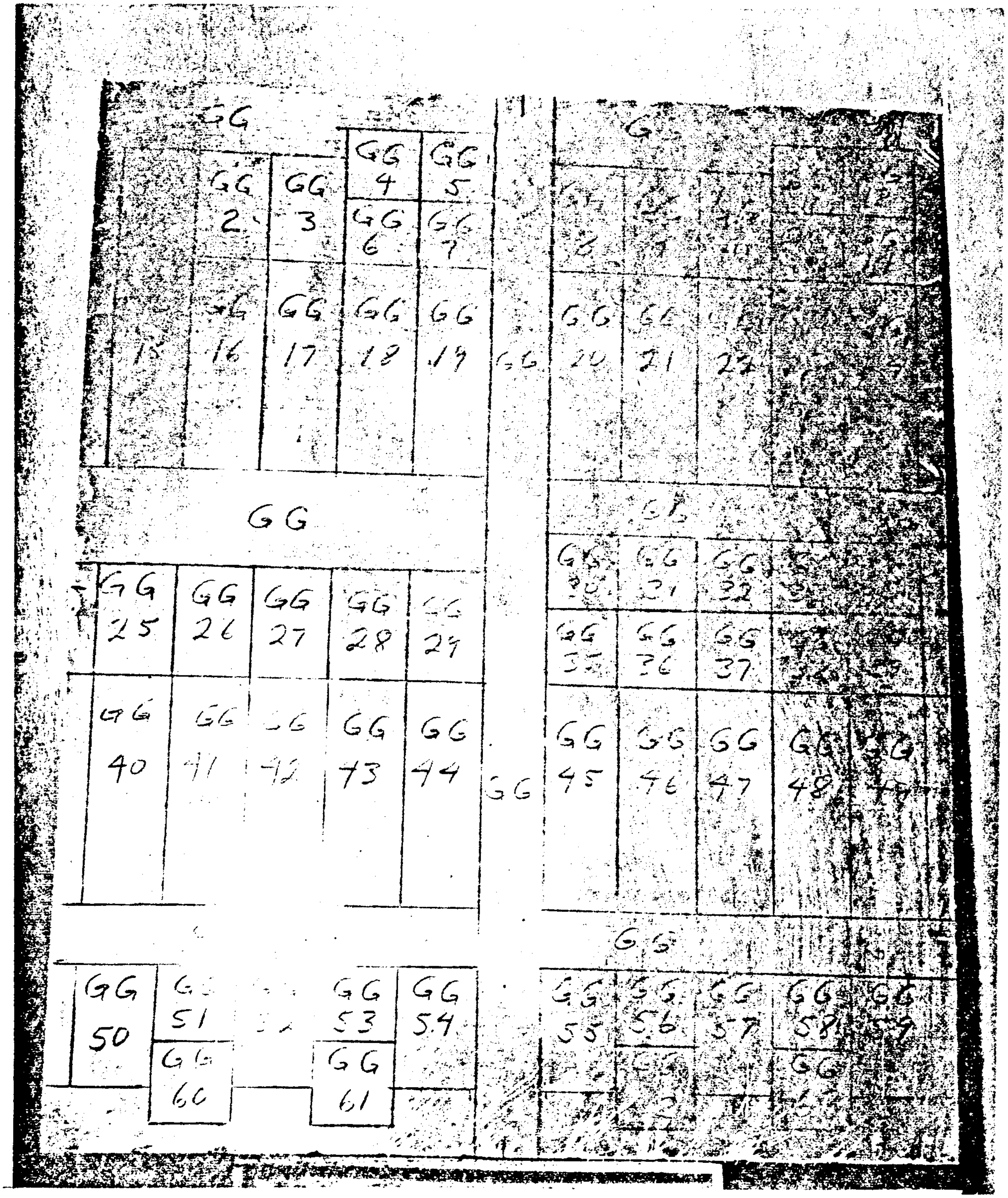


Figure 63 - Brazed sandwich Panel GG showing specimen layout.

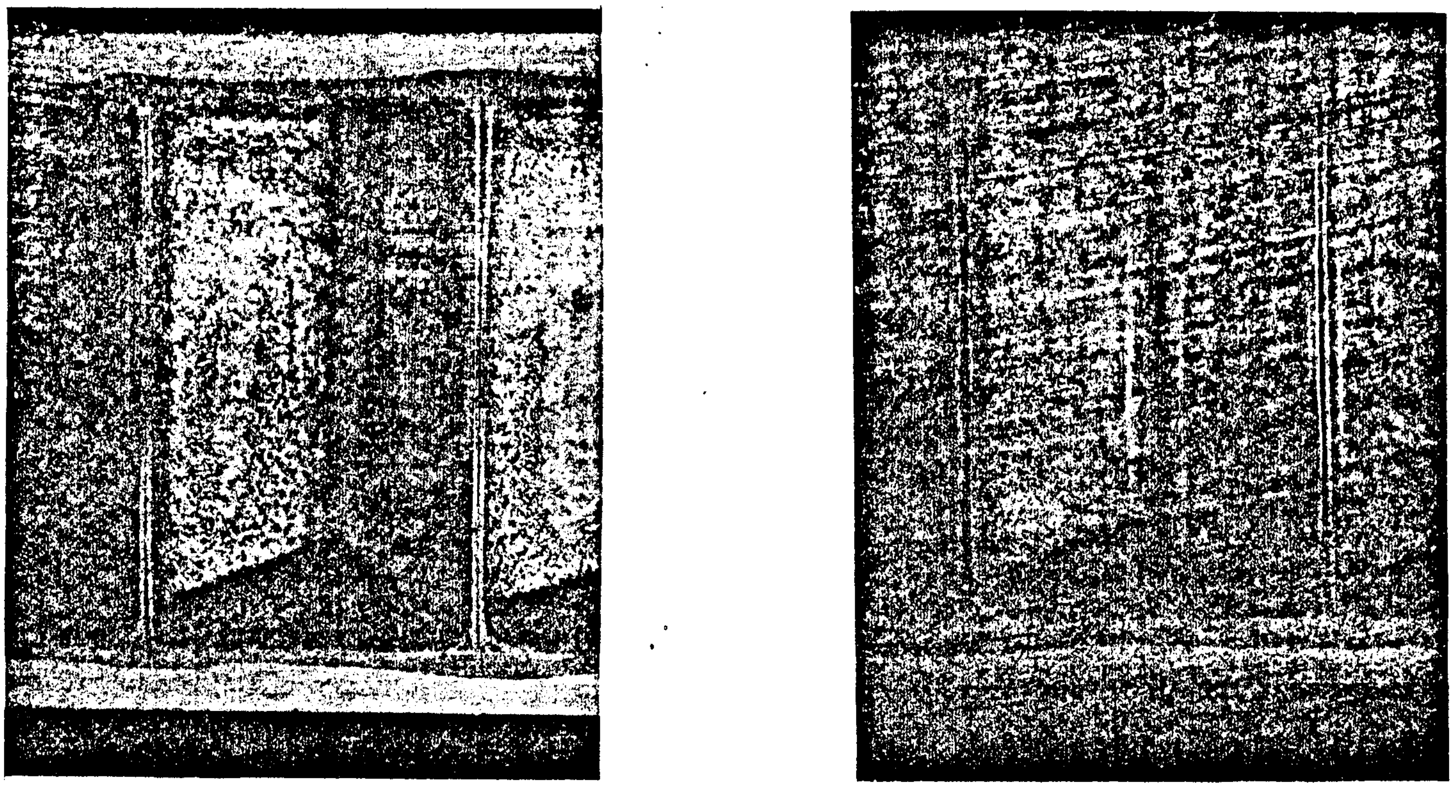


Figure 64 - Left: Section from Brazed Panel G showing brazing alloy diffusion into face sheets and partial brazing alloy node flow.

Right: Section from Brazed Panel G showing brazing alloy diffusion into face sheets and no brazing alloy node flow.

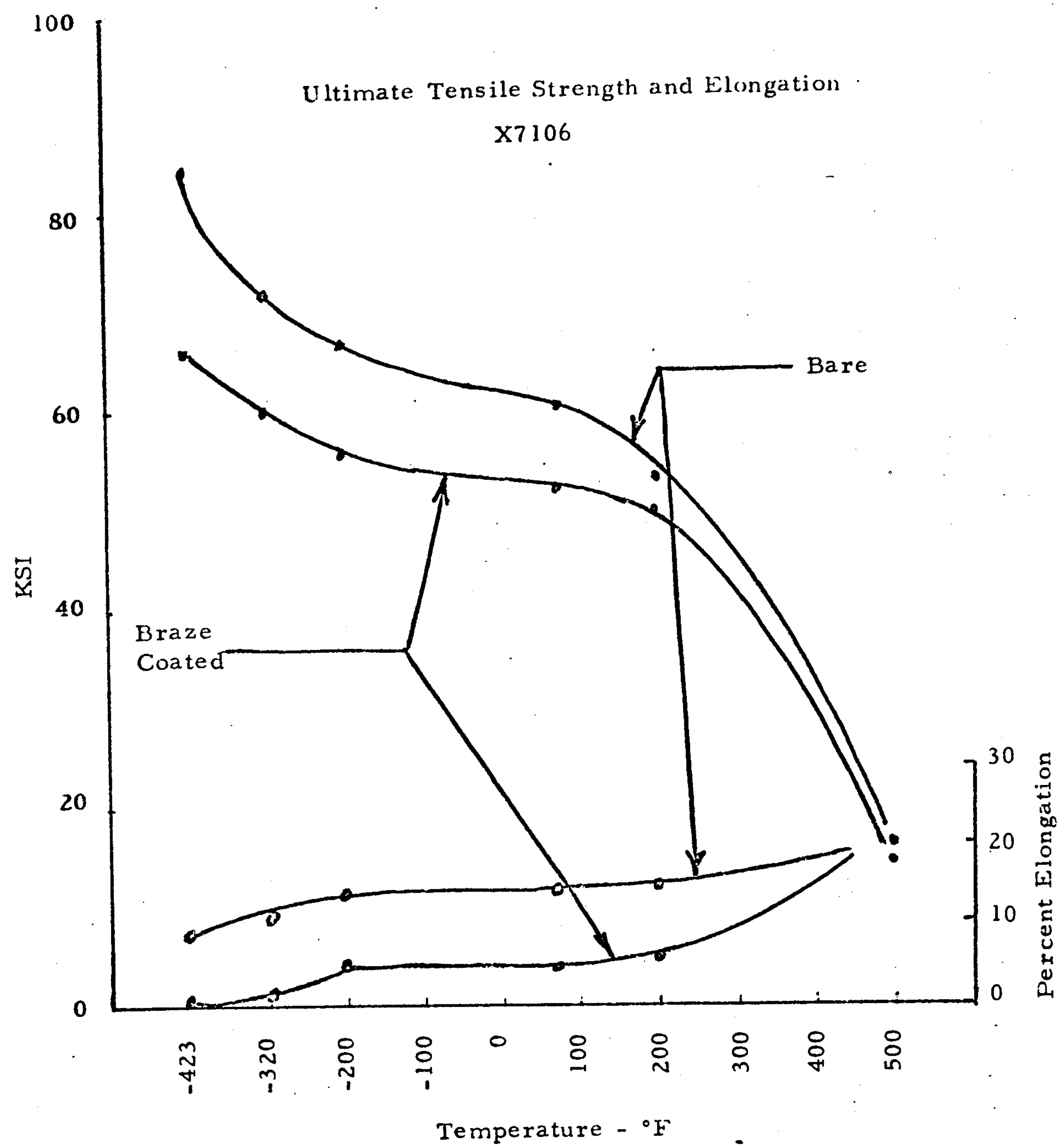


Figure 65- Tensile properties of brazed sandwich facings and facing extensions (bare). The brazing alloy was No. 719.

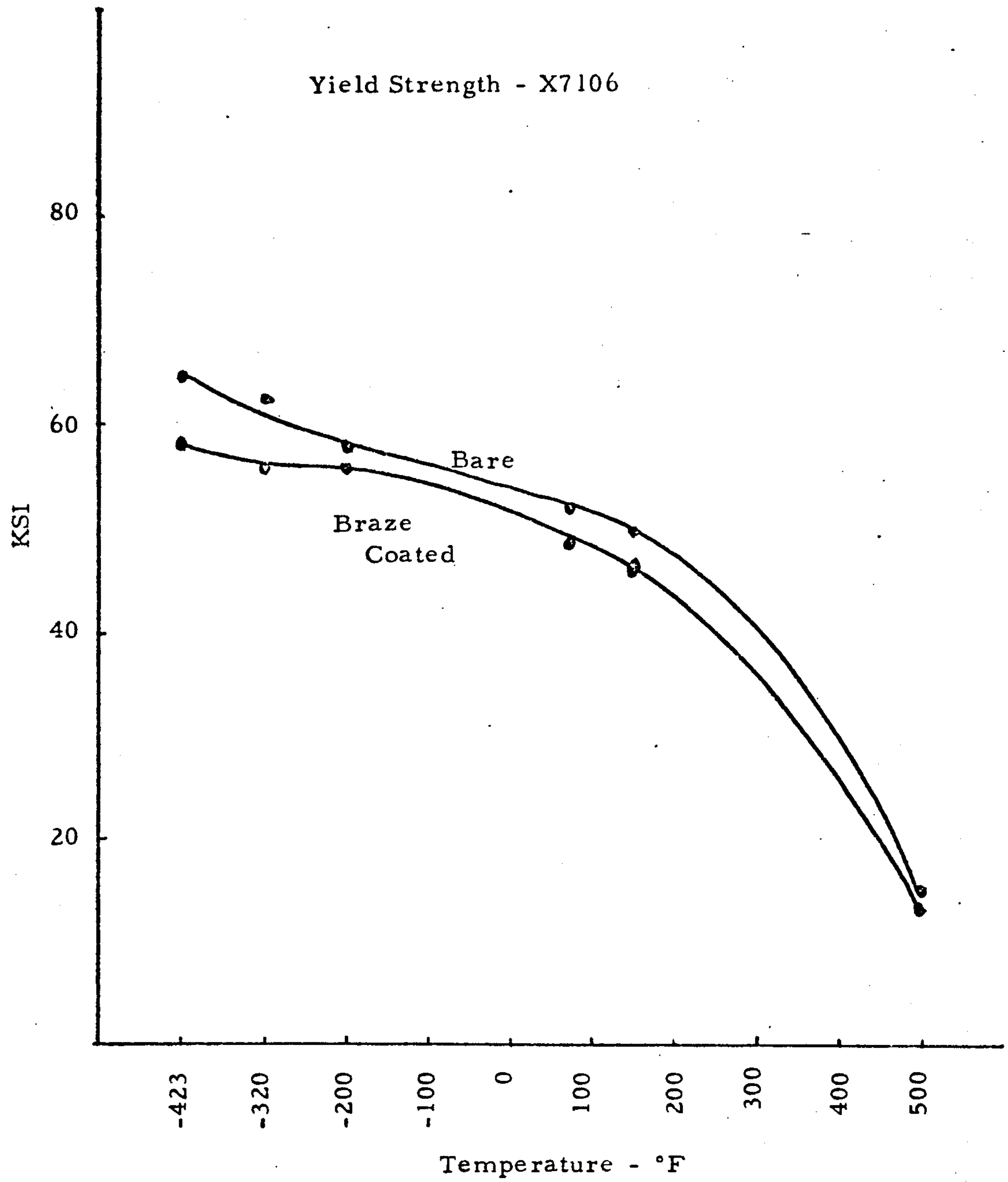


Figure 66 - Tensile properties of brazed sandwich facings and facing extensions (bare). The brazing alloy was No. 719.

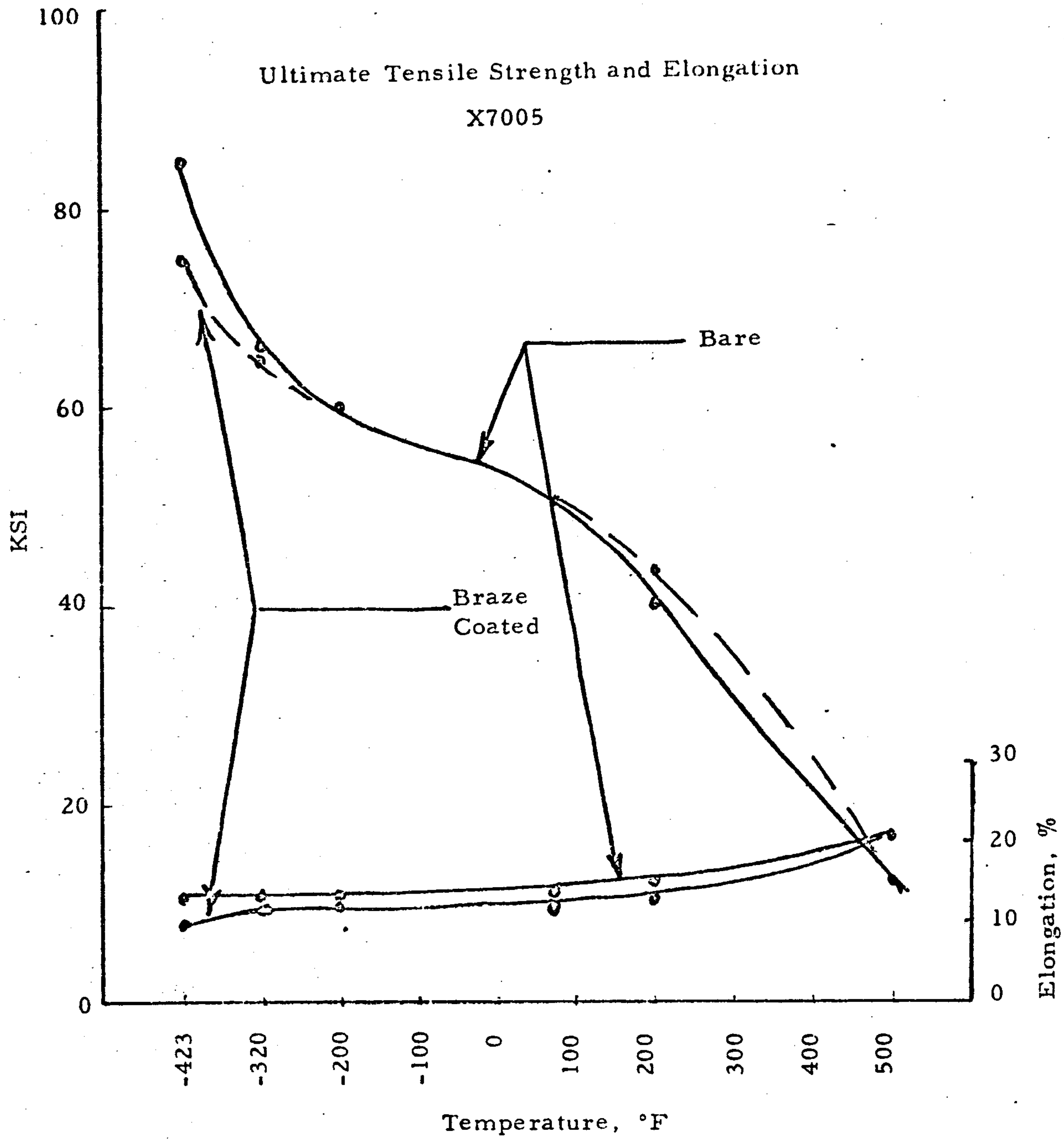


Figure 67 - Tensile properties of brazed sandwich facings and facing extensions (bare). The brazing alloy was No. 719.

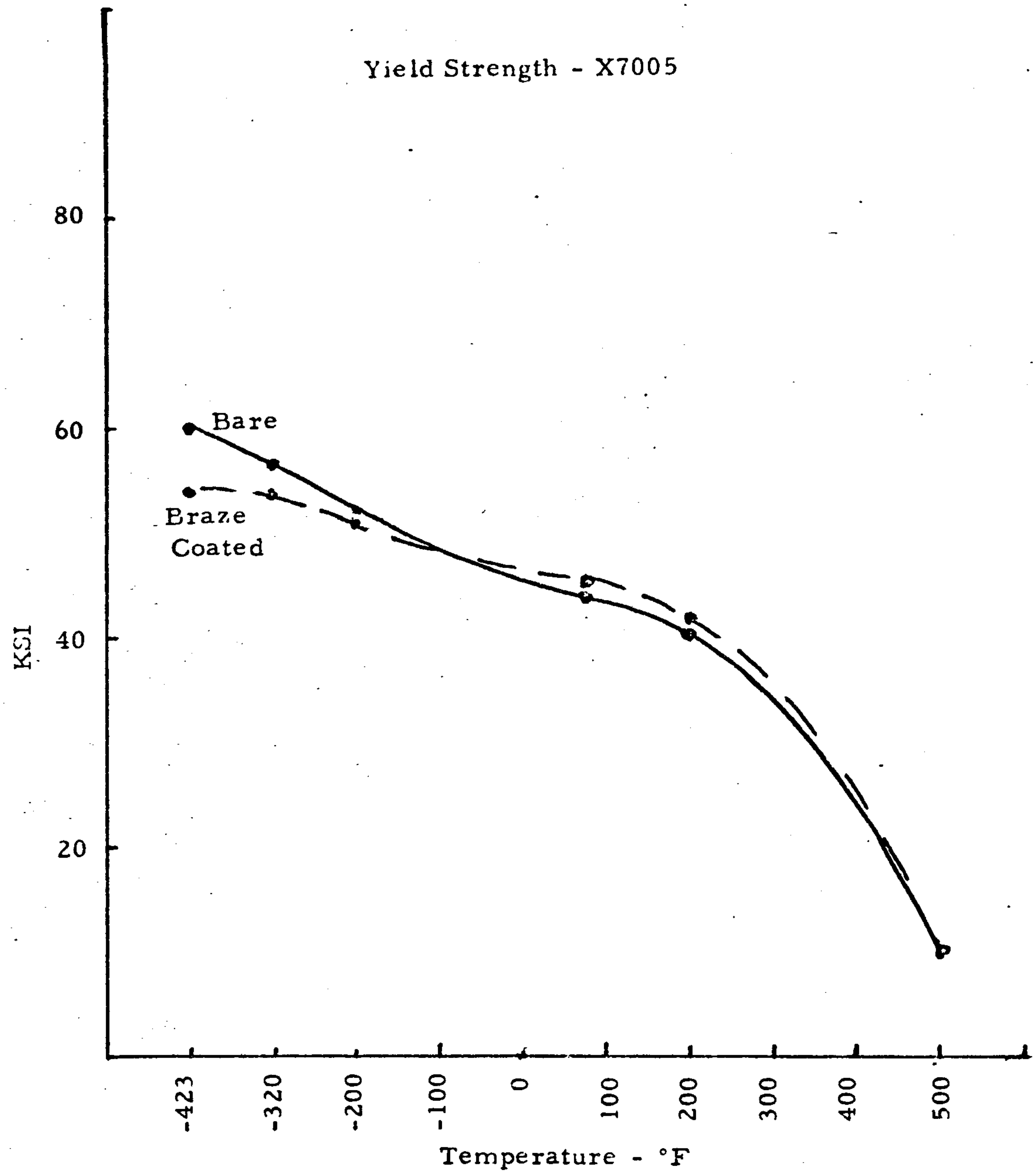


Figure 68 - Tensile porperties of brazed sandwich facings and facing extensions (bare). The brazing alloy was No. 719.

PUBLISHED ALCOA DATA

X7005-T6	Room Temperature Minimum	Room Temperature Typical
F_{tu}, ksi	45	51
F_{ty}, ksi	36	42
Elongation, %	7	13

X7106-T6	Room Temperature Minimum	Room Temperature Typical
F_{tu}, ksi	55	61
F_{ty}, ksi	50	55
Elongation, %	6	13

Figure 69 - Published Tensile Data on Alloys X7106 and X7005

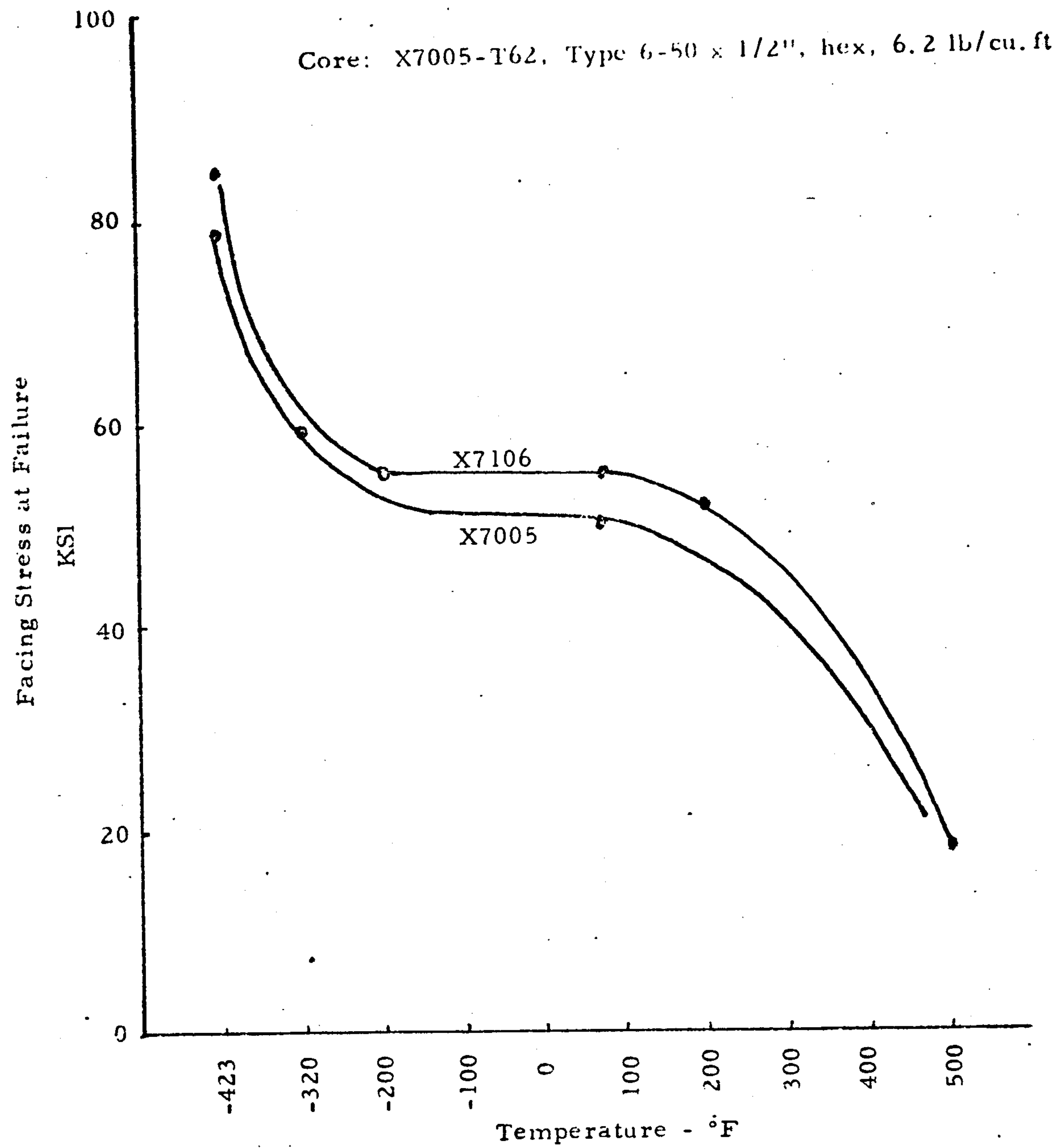


Figure 70 - Edgewise Compressive Strength of Brazed Aluminum Honeycomb Core Sandwiches

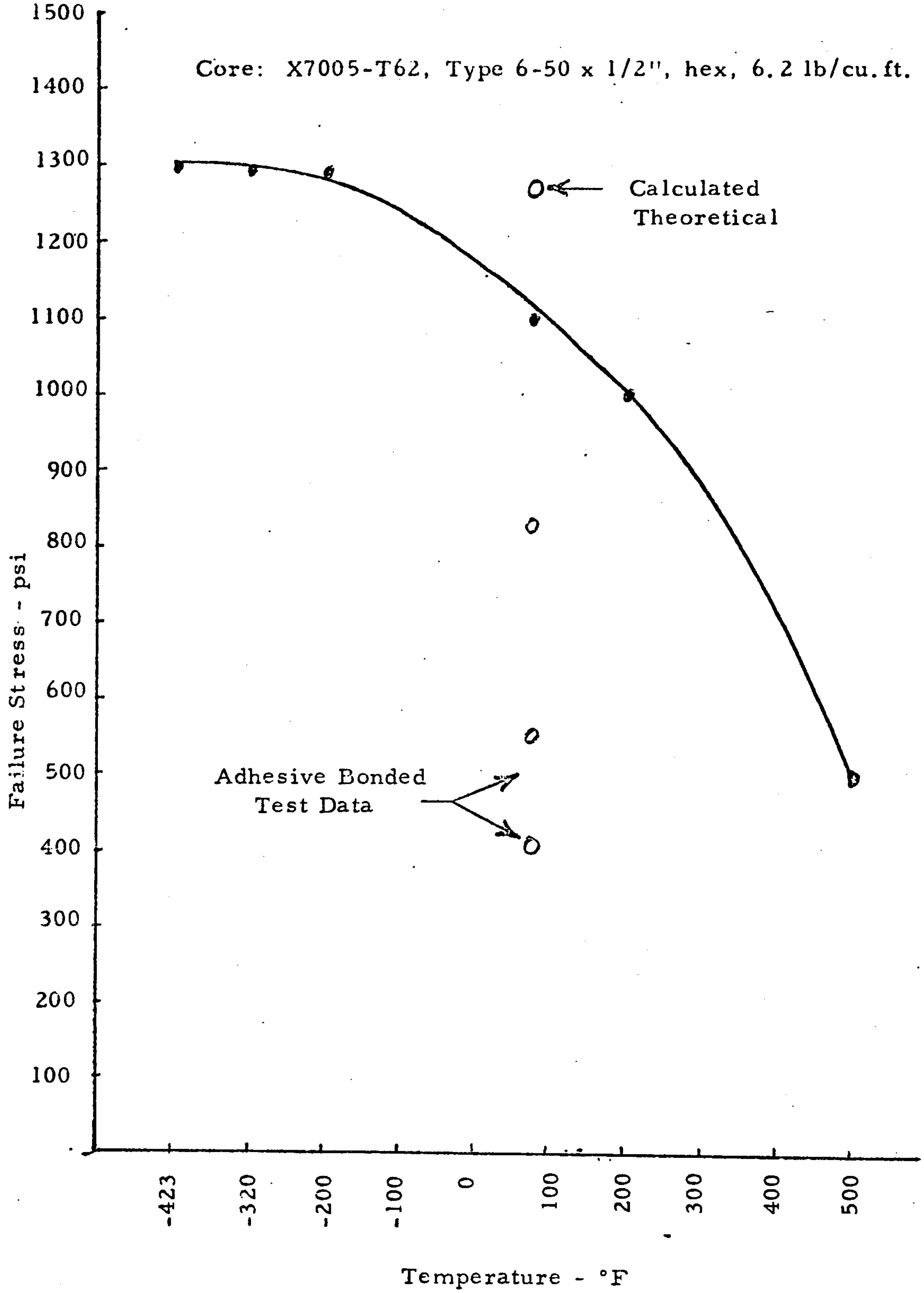


Figure 71 - Flatwise Tensile Strength of Brazed Aluminum Honeycomb Core Sandwiches

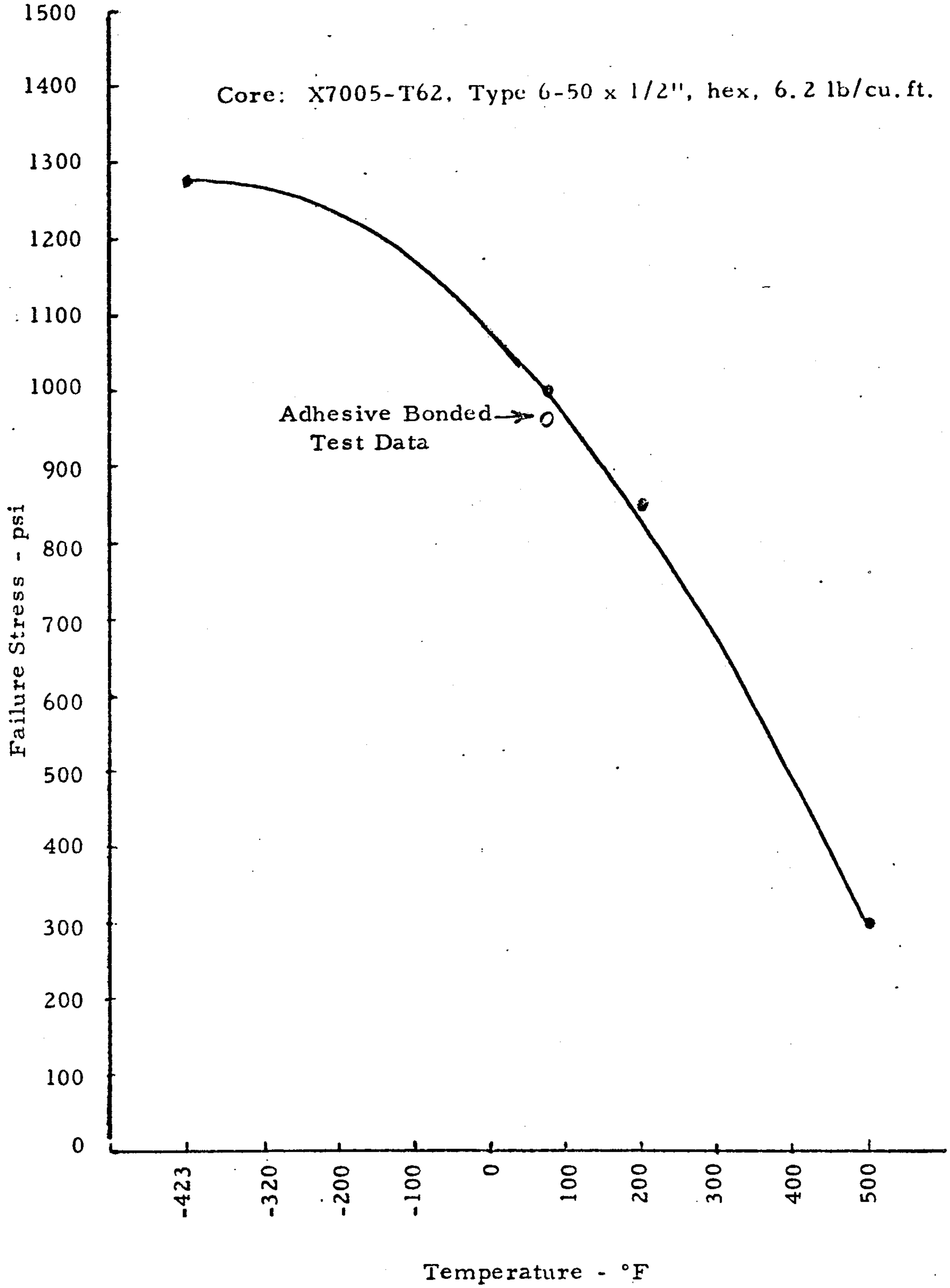


Figure 72 - Flatwise Compressive Strength of Brazed Aluminum Honeycomb Core Sandwiches

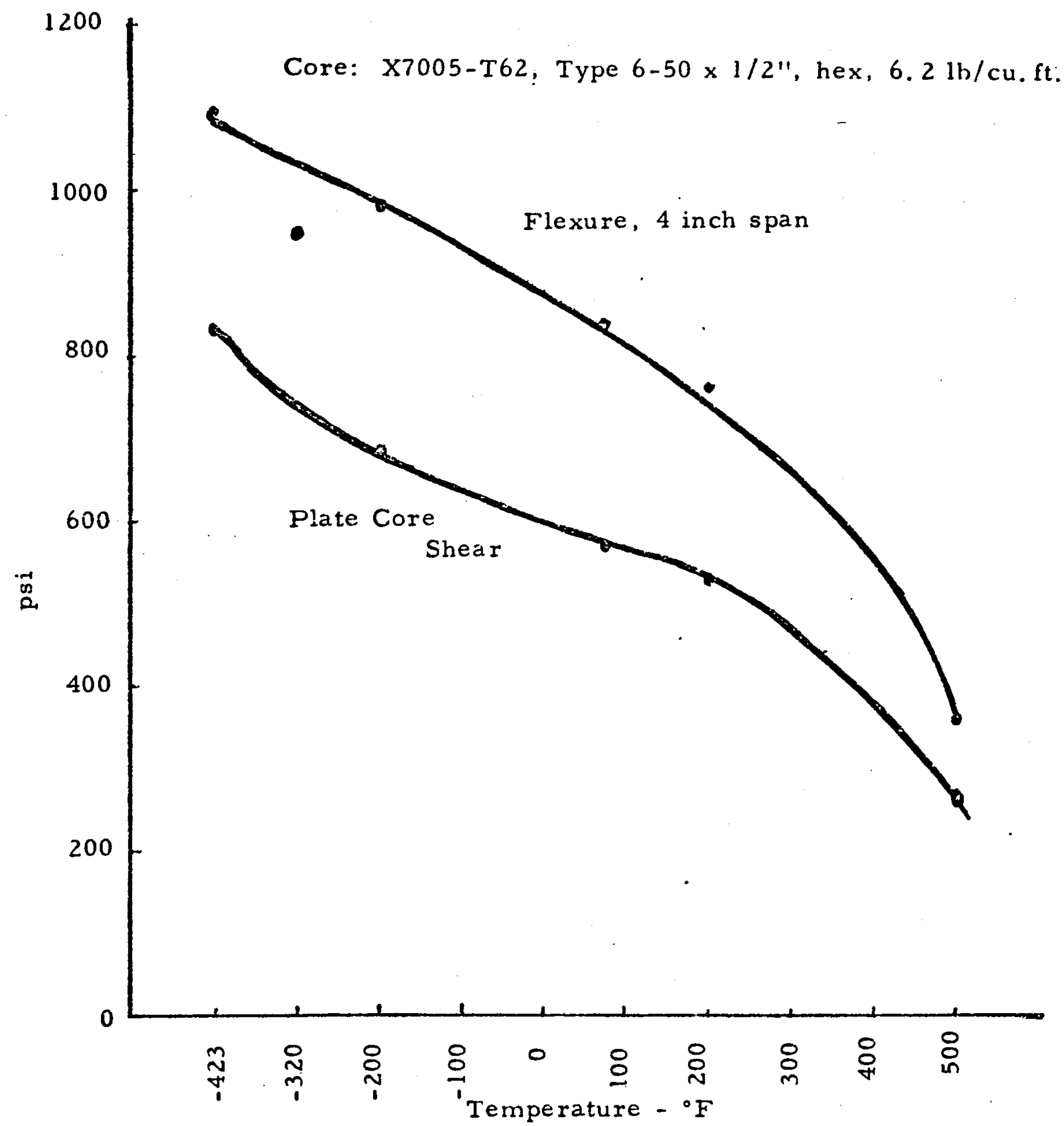


Figure 73 - Core Shear Strength of Brazed Aluminum Honeycomb Core Sandwiches

TABLE 27

TEST DATA SUMMARY

		Brazed Panel F X7005 Faces X7005 Core Type 6-50 x 1/2"	Brazed Panel G X7106 Faces X7005 Core Type 6-50 x 1/2"	Brazed Panel GG X7106 Faces X7005 Core Type 6-50 x 1/2"	Calculated Data Appendix A X7005 Core Type 6-50
Sandwich Facing Extension, psi	F_{tu}	52,000	59,000	60,000	-
	F_{ty}	44,000	51,000	52,000	-
Sandwich Facing, psi (Coated with brazing alloy)	F_{tu}	50,000	53,000	53,000	
	F_{ty}	44,000	48,000	48,000	-
Sandwich Edgewise Compression Ult. Facing Strength, psi		51,000	50,000	61,000	-
Sandwich Flatwise Compressive Strength, psi		770	1,000	950	620
Sandwich Flatwise Tensile Strength, psi		860	950	1,140	1,270
Plate Core Shear Strength, L Direction, psi		500	580	635	560
Plate Core Shear Modulus, L Direction, psi		87,000	200,000	114,000	55,000

TABLE 28

TENSILE DATA - PANELS G & GG
FACING EXTENSION

Bare X7106, 0.062" thick.
Solutioned at 875°F, quenched into liquid nitrogen, aged 1 day at room temperature and 96 hrs. at 250°F.

Specimen Number	Test Temp. °F	Ultimate Tensile Strength psi	Yield Strength 0.2% Offset psi	Elongation Percent
G	-423	83,700	Not available	8
G		82,500	60,500	6
G		80,700	67,100	6
GG		82,500	65,800	8
GG		90,800	Not available	6
GG		84,600	67,100	6
G	-320	71,600	61,400	13
GG		71,700	62,100	13
GG		72,700	63,500	11
GG		74,800	64,100	12
GG		73,500	65,000	11
GG		72,200	60,700	11
G	-200	66,600	59,100	14
GG		67,700	59,400	14
GG		66,400	56,900	14
GG		65,300	56,800	14
GG		68,800	59,000	14
GG		67,000	58,700	14
G	R.T.	59,500	51,600	13
G		59,400	51,100	14
G		59,000	51,600	15
GG		60,600	52,700	12
GG		60,500	53,100	12
GG		58,900	51,300	14
G	200	53,400	49,800	13
G		56,500	51,500	12
GG		53,500	47,400	16
GG		56,000	50,400	15
GG		53,700	50,000	14
GG		53,500	50,200	14
GG	500	13,400	11,800	12
GG		16,200	14,300	16
GG		13,200	12,200	25
GG		20,000	17,500	12
GG		15,000	13,000	15
GG		19,000	17,900	19

TABLE 29

FACING TENSILE DATA - BRAZED PANELS G & GG

X7106, 0.062" thick, coated with brazing alloy No. 719
Solutioned at 875°F, quenched into liquid nitrogen, aged 1 day at room temperature and 96 hours at 250°F.

Specimen Number	Test Temp. °F	Ultimate Tensile Strength psi	Yield Strength 0.2% Offset psi	Elongation Percent
G	-423	62,500	54,600	0.5
G		71,100	Not available	0.5
G		69,200	Not available	2
GG		65,300	59,500	2
GG		67,400	62,800	2
GG		62,139	53,100	2
G	-320	58,100	54,900	3
G		60,800	55,700	3
GG		59,700	56,100	2
GG		60,400	56,000	3
GG		58,900	54,500	2
GG		63,900	57,600	5
G	-200	55,000	53,000	3
G		57,800	53,100	4
GG		59,400	57,800	4
GG		59,600	54,400	5
GG		56,900	53,600	3
GG		61,400	54,800	5
G	R.T.	51,300	47,300	4
G		52,700	48,100	5
G		53,900	50,000	1
GG		52,100	47,100	4
GG		54,700	49,700	4
GG		53,200	47,300	3
G	200	47,400	44,400	3
G		49,100	45,300	3
GG		49,700	44,800	8
GG		51,600	46,100	6
GG		50,200	46,500	4
GG		49,900	44,900	5
G	500	12,800	11,300	20
GG		20,800	19,800	12
GG		12,700	10,200	30

TABLE 30

TENSILE DATA- PANELS F & FF
FACING EXTENSION

Bare X7005, 0.064" thick
Solutioned at 1060°F by a brazing cycle, air quenched to room temperature at a rate of approx. 20°F per minute, and aged 7 days at room temperature and 96 hrs. at 250°F.

Specimen Number	Test Temp. °F	Ultimate Tensile Strength psi	Yield Strength 0.2% Offset psi	Elongation Percent
F	-423	86,600	62,300	20
F		84,900	60,800	19
F		85,800	55,600	16
FF		Not available	59,500	8
FF		85,300	Not available	8
FF		83,900	Not available	9
F	-320	64,600	55,100	11
F		67,800	58,000	13
F		67,300	56,800	13
FF		64,500	54,600	13
FF		65,400	54,800	14
FF		64,700	54,600	14
F	-200	60,700	53,200	12
F		60,700	50,600	13
F		61,700	50,600	12
FF		59,400	52,500	13
FF		59,300	51,100	13
FF		59,100	50,600	14
F	R.T.	51,700	43,800	13
F		50,000	45,300	13
F		53,100	44,500	14
FF		49,500	44,400	13
FF		49,500	43,400	13
FF		48,800	41,600	13
F	200	45,200	41,300	12
F		45,900	41,100	13
F		48,500	43,900	15
FF		43,700	36,700	15
FF		44,800	36,700	15
FF		45,000	41,500	14
F	500	9,500	7,100	23
F		10,000	7,600	22
F		12,200	8,000	14
FF		12,600	11,600	19
FF		12,900	12,000	23
FF		14,700	14,000	18

TABLE 31

FACING TENSILE DATA - BRAZED PANELS F & FF

X7005, 0.064" thick, coated with brazing alloy No. 719. Solutioned at 1060°F by a brazing cycle, air quenched to room temperature at a rate of approximately 20°F per minute, and aged 7 days at room temperature and 96 hours at 250°F.

Specimen Number	Test Temp. °F	Ultimate Tensile Strength psi	Yield Strength 0.2% Offset psi	Elongation Percent
F	-423	80,300	56,100	12
F		70,300	56,300	12
F		78,800	48,300	16
FF		Not available	Not available	Not available
FF		65,500	52,900	7
FF		78,400	56,700	14
F	-320	64,400	51,000	14
F		65,600	54,100	14
F		64,900	56,400	11
FF		63,400	56,800	14
FF		64,000	54,000	14
FF		65,000	56,000	13
F	-200	59,400	49,800	13
F		59,900	49,500	9
F		59,800	49,300	13
FF		59,000	50,000	14
FF		60,400	53,700	14
FF		58,800	51,500	14
F	R.T.	53,500	44,500	12
F		52,800	47,700	12
F		51,200	45,500	9
FF		51,500	42,000	11
FF		53,900	45,300	10
FF		55,400	49,800	13
F	200	45,000	41,100	15
F		45,200	39,800	11
F		43,100	39,100	12
FF		44,500	41,100	13
FF		45,000	42,700	14
FF		44,800	42,600	12
F	500	10,600	10,400	10
F		9,200	8,300	15
F		17,700	16,700	14
FF		14,900	12,500	8
FF		11,400	8,100	23
FF		12,300	10,800	25

TABLE 32

EDGEWISE COMPRESSION TESTS
BRAZED SANDWICH SPECIMENS G & GG

Faces: X7106
Core: X7005, Type 6-50 x 1/2", Hexagonal Cell
Brazing Alloy: No. 719
Nominal Specimen Size: 0.6" x 2" x 3"
Test Direction and Core Direction were parallel with the 3" dimension

Specimen Number	Test Temp. °F	Facing Stress at Failure - psi	Failure Mode
G-2	-423	78,100	
G-58		82,600	
GG-2		92,500	
GG-8		83,200	
GG-29		84,800	
GG-52		88,500	
G-3	-320	56,000	Face separation
G-6		56,800	Face separation
GG-25		57,400	Face wrinkling outward
GG-1		64,500	Shear crimping
G-1	-200	53,300	Face wrinkling outward
G-63		54,700	Face separation
GG-27		57,900	Face separation
G-8	R.T.	47,800	Shear crimping
G-40		51,000	Shear crimping
G-51		50,400	Shear crimping
GG-9		64,500	Shear crimping
GG-28		60,100	Shear crimping
GG-54		59,500	Face separation
G-7	200	50,300	Shear crimping
GG-10		51,900	Shear crimping
GG-26		52,900	Shear crimping
G-64	500	18,200	Shear crimping
G-52		17,600	Shear crimping
GG-50		17,400	Shear crimping

TABLE 33

EDGEWISE COMPRESSION TESTS
BRAZED SANDWICH SPECIMENS F

Faces: X7005
Core: X7005, Type 6-50 x 1/2", Hexagonal Cell
Brazing Alloy: No. 719
Nominal Specimen Size: 0.6" x 2" x 3"
Test Direction and Core Direction were parallel with the 3" dimension.

Specimen Number	Test Temp. °F	Facing Stress at Failure - psi	Failure Mode
F-2	-423	76,800	
F-4		78,300	
F-29		79,600	
F-1	R.T.	53,500	Shear crimping
F-6		51,100	Shear crimping
F-36		47,600	Face separation

TABLE 34

FLATWISE TENSILE TESTS
BRAZED SANDWICH SPECIMENS G & GG

Faces:	X7106
Core:	X7005, Type 6-50 x 1/2", Hexagonal Cell
Brazing Alloy:	No. 719
Nominal Specimen Size:	0.6" x 1.5" x 2"

Specimen Number	Test Temp. °F	Failing Stress psi	Failure Mode
G-21	-423	1030	
G-47		1820	
GG-6		1380	
GG-39		1190	
GG-42		680	
GG-51		1660	
G-53	-320	>1130	Core tear & tooling adhesive
GG-58		1370	Braze & core tear
GG-13		1520	Core tear
G-32	-200	1180	Core tear
GG-14		1190	Core tear
GG-34		1290	Core tear
G-16	R. T.	> 600	Core tear & tooling adhesive
G-62		> 620	Core tear & tooling adhesive
G-4		> 1060	Core tear & tooling adhesive
G-20		1130	Core tear
G-50		1320	Core tear
GG-31		1050	Braze & core tear
GG-32		1060	Core tear
GG-35		1300	Core tear
G-31	200	770	Braze void & core tear
G-33		1000	Core tear
GG-61		1090	Core tear
G-22	500	480	Core tear
G-54		470	Core tear
GG-55		500	Core tear

TABLE 35

FLATWISE TENSILE TESTS
BRAZED SANDWICH SPECIMENS F

Faces: X7005
Core: X7005, Type 6-50 x 1/2", Hexagonal Cell
Brazing Alloy: No. 719
Nominal Specimen Size: 0.6" x 1.5" x 2"

Specimen Number	Test Temp. °F	Failing Stress psi	Failure Mode
F-3	-423	1580	
F-9		1350	
F-49		1400	
F-48	R.T.	1080	Core tear
F-59		1080	Core tear
F-62		430	Braze void & core tear
F-19		970	Core tear

TABLE 36

Room Temperature Flatwise Tensile Strength

Various Adhesive Bonded Sandwich Data

Honeycomb[1] Core Size	Honeycomb[2] Core Density lb/cu. ft.	Adhesive	Flatwise[3] Tensile Strength psi
6 - 80	8.2	FM 1000[4]	830
6 - 80, sq. cell	7.0	FM 1000[4]	550
4 - 40	7.9	Metlbond 328[5]	1000
4 - 30	6.0	HT 424[6]	714
4 - 40	7.9	HT 424[7]	1200
6 - 50	6.2	HT 424[8]	400

NOTES

(1) Hexagonal cell configuration unless otherwise noted.

(2) Aluminum alloys. High density cores generally are used to evaluate the adhesive, but not fail the core; consequently, the alloy type is not specified and the failure mode is assumed to be an adhesive failure.

(3) Test data or "Typicals".

(4) Aeronca test data, ER-802, January 1965.

(5) Suppliers technical data, Narmco Materials Division.

(6) Suppliers technical data, Bloomingdale Rubber Co.

(7) Aeronca test data, ER-755, January 1964.

(8) Aeronca test data

TABLE 37

FLATWISE COMPRESSION TESTS
BRAZED SANDWICH SPECIMENS G & GG

Faces: X7106
Core: X7005, Type 6-50 x 1/2", Hexagonal Cell
Brazing Alloy: No. 719
Nominal Specimen Size: 0.6" x 2" x 2"

Specimen Number	Test Temp. °F	Failing Stress psi	Remarks
G-30	-423	1320	
G-46		1330	
GG-4		1340	
GG-12		1450	
GG-37		1030	
GG-60		1200	
G-45	-320	800	Not uniformly loaded.
GG-7		910	
GG-53		840	
G-10	-200	480	Not uniformly loaded.
GG-5		710	
GG-62		730	
G-5	R. T.	850	
G-15		1090	
G-48		1100	
GG-30		930	
GG-33		960	
GG-36		970	
G-44	200	810	
GG-38		920	
GG-63		830	
G-60	500	260	
GG-11		310	
GG-56		250	

TABLE 38

FLATWISE COMPRESSION TESTS
BRAZED SANDWICH SPECIMENS F

Faces:	X7005
Core:	X7005, Type 6-50 x 1/2", Hexagonal Cell
Brazing Alloy:	No. 719
Nominal Specimen Size:	0.6" x 2" x 2"

Specimen Number	Test Temp. °F	Failing Stress psi	Remarks
F-46	-423	1290	
F-52		570	
F-65		620	
F-38	R. T.	740	
F-45		810	
F-66		770	

TABLE 39

FLATWISE COMPRESSION TESTS
ADHESIVE BONDED SANDWICH SPECIMENS

Faces: X7005
Core: X7005-T62, Type 6-50 x 1/2", Hexagonal Cell
Adhesive: HT 424
Nominal Specimen Size: 0.6" x 2" x 2"

Specimen Number	Test Temp. °F	Failing Stress psi	Remarks
1	R. T.	1010	
2		930	
3		930	

TABLE 40

PLATE CORE SHEAR TESTS

BRAZED PANELS G & GG

Faces:	X7106
Core:	X7005, Type 6-50 x 1/2", Hexagonal Cell
Brazing Alloy:	No. 719
Nominal Specimen Size:	0.6" x 2" x 6"

Specimen Number	Test Temp. °F	Core Shear Stress psi	Core Shear Modulus psi
G-35	-423	860	58,400
G-66		840	50,500
GG-17		860	61,300
GG-24		910	58,300
GG-40		750	48,600
GG-46		820	61,300
G-27	-320	>360	Tooling adhesive failed.
GG-13		>300	
GG-44		>100	
G-29	-200	720	
G-2		640	
GG-19		>550	Tooling adhesive failed.
G-36	R.T.	520	130,000
G-19		620	>200,000
G-39		610	200,000
GG-18		670	120,000
GG-22		600	110,000
GG-45		610	125,000
G-25	200	540	
G-65		520	
GG-54A		540	
G-1	500	250	
GG-20		260	

TABLE 41

PLATE CORE SHEAR TESTS

BRAZE PANEL F

Faces:	X7005
Core:	X7005, Type 6-50 x 1/2", Hexagonal Cell
Brazing alloy:	No. 719
Nominal Specimen Size:	0.6" x 2" x 6"

Specimen Number	Test Temp. °F	Core Shear Stress psi	Core Shear Modulus psi
F-32	-423	730	58,400
F-33		860	46,600
F-22	R.T.	450	90,000
F-34		520	83,000
F-55		550	88,500

TABLE 42

BEAM FLEXURE TESTS
BRAZED SANDWICH SPECIMENS G & GG

Faces:	X7106
Core:	X7005, Type 6-50 x 1/2", Hexagonal Cell
Brazing Alloy:	No. 719
Nominal Specimen Size:	0.6" x 2" x 6"
Loading:	Four inch span, loaded at two quarter-span points.

Specimen Number	Test Temp. °F	Core Shear Stress psi	Core Shear Modulus psi
G-24	-423	1120	
G-38		1160	
GG-15		1270	
GG-23		1120	
GG-42		1010	
GG-48		1100	
G-57	-320	1020	
GG-41		880	
GG-43		950	
G-18	-200	1010	
G-56		980	
GG-47		950	
G-14	R. T.	890	
G-28		900	
G-37		940	
GG-16		910	
GG-49		890	
G-12	200	730	
G-17		810	
G-26		730	
G-4	500	390	
G-15		340	

TABLE 43

BEAM FLEXURE TESTS
BRAZED SANDWICH SPECIMENS F

Faces:	X7005
Core:	X7005, Type 6-50 x 1/2", Hexagonal Cell
Brazing Alloy:	No. 719
Nominal Specimen Size:	0.6" x 2" x 6"
Loading:	Four inch span, loaded at two quarter-span points.

Specimen Number	Test Temp. °F	Core Shear Stress psi	Core Shear Modulus psi
F-5	-423	920	
F-15		990	
F-58		1100	
F-20	R.T.	710	
F-56		700	
F-57		770	

strengths and ductilities of the materials met the supplier's specification for condition T6, minimum; consequently, the heat treatements were acceptable (quench rates were slower than the recommended rates).

The effect of the brazing alloy (and processing time) on the substrates, X7106 and X7005, is clearly evident and confirms the metallographic examination. X7005 was substantially unaffected but X7106 showed a significant loss in ultimate tensile strength and elongation as the detrimental result of brazing alloy diffusion.

Sandwich Properties

The X7005 honeycomb core foil, 0.005" thick, responded acceptably to both the brazing process and the mechanical tests, as evidenced by the various sandwich tests. Edgewise compression specimens were stabilized to the expected compressive yield strengths of the materials. Similarly, flatwise tensile and flatwise compressive strengths were acceptable and flatwise tensile, in particular, substantially exceeded the strengths of adhesive bonded specimens.

Detailed examination of the data in the tables shows some brazed voids, indicating a need for quality control improvements. However, the brazing alloy foil was imperfect and difficult to assemble in the sandwich layup. Many of the voids could be attributed to those brazing alloy imperfections.

The core shear properties determined from plate core shear tests consistently achieved the theoretical core shear strength and are inherently more accurate than shear properties determined from flexure tests.

Core shear modulus values, an important sandwich parameter, compare favorably with calculated values. A comparison of predicted honeycomb sandwich properties and test results appear in Table 27.

Core shear modulus values from sandwich specimens with node flow (Panel G) were substantially higher than those from panels without node flow, confirming test results from Panel AA (reported in Section 2.1).

2.4 BRAZED X7106 USING TWO NEWLY DEVELOPED BRAZING ALLOYS

Honeycomb core sandwich panels were brazed with two experimental brazing alloys, whose development is reported in Volume I. The selected sandwich materials were X7106 for panel faces and X7005 honeycomb core, type 6-50x½". The brazing alloys were 68Al-15Ge-7Si-10Zn and 68Al-15Ge-7Si-10Ag.

Table 45 lists the panels which were brazed and their identification.

Panel assembly was done as previously described. Stainless steel retorts were used. The honeycomb core was fabricated as previously described, except for the core with brazing alloy pre-placed in the core nodes. Strips of brazing alloy were cut slightly larger than the node land and welded in place during the node welding. A photograph of one of those core blankets is shown in Figure 74.

Brazing was done in a new, embedded wire type, electrically heated, ceramic brazing die, which provided fast heating rates and excellent temperature control. Heating from room temperature to the brazing temperature required 40 minutes. The retorts were instrumented with weld-on external thermocouples on both faces. The brazing cycle was 15 minutes within the specified temperature range and the total temperature spread was 10°F.

Panels H and HH were quenched into a container of liquid nitrogen immediately following brazing as shown in Figure 75. This was done by elevating the top half of the die, removing the retort, and plunging it into the nitrogen; the time required for that action was approximately ten seconds for Panel H. Warpage occurred in the following manner: Panel H was hemispherical in shape, approximately 3/4" out of flat over a 12" chord. An analysis of the thermocouple plot showed that the bottom face of the retort, lying horizontal, in the quench tank, lagged the top face by 200° to 300°F in cool down rate to room temperature. The mode of warpage was bottom face concave (the warmer face), top face convex, (the cooler face).

The procedure planned for panel HH was to remove it from the die and air cool it to 900°F before submerging it into liquid nitrogen and agitate it while in the nitrogen. After panel HH was out of die for 45 seconds, it was observed to bow, with the top face convex. It was immediately inverted and plunged into liquid nitrogen. The panel was irregularly warped, but the predominate mode was convex up - as originally withdrawn from the die. An analysis of thermocouple plots showed that within the first 30 seconds, it was out of the die, the top face cooled 30° to 50°F more than the bottom face.

Table 44

PANELS BRAZED, BRAZING METHOD AND RESULTS

Code	Materials	Brazing Temperature and Alloy	Brazing Tooling* & Method	Result
H	X7106 Faces X7005 Core	1010-1020°F Al-Ge-Si-Zn	Ceramic Brazing Die Quenched into Liq. N_2 from 1000°F	80% Brazed Owing to warpage
HH	X7106 Faces X7005 Core with Brazing Alloy Pre-placed in Core Nodes	1010-1020°F Al-Ge-Si-Zn	Ceramic Brazing Die Quenched into Liq. N_2 from 1000°F	80% Brazed Owing to warpage
J	X7106 Faces X7005 Core with Brazing Alloy Pre-placed in Core Nodes	1020-1040°F Al-Ge-Si-Ag	Ceramic Brazing Die and Cooled in Die Post Brazed Heat Treated by Quenching from 900°F into Liq. N_2	100% Brazed Flat, but partly crushed core

*All panels were aged one day at room temperature and 96 hours at 250°F.

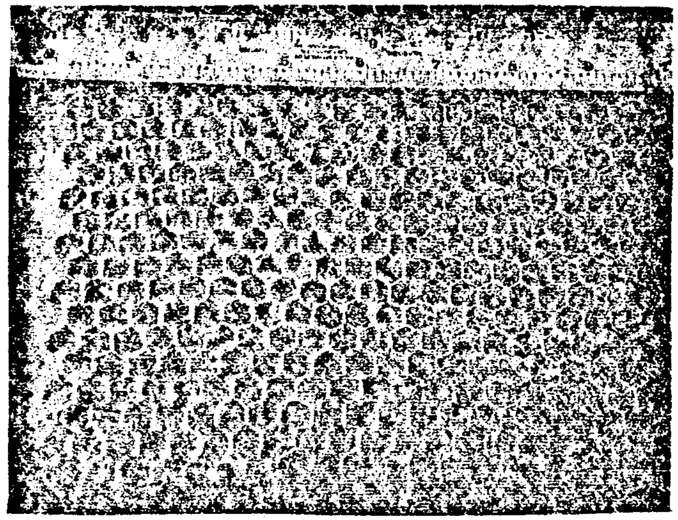


Figure 74 - X7005 Honeycomb Core Blanket Fabricated with Brazing Alloy Pre-positioned in Core Nodes

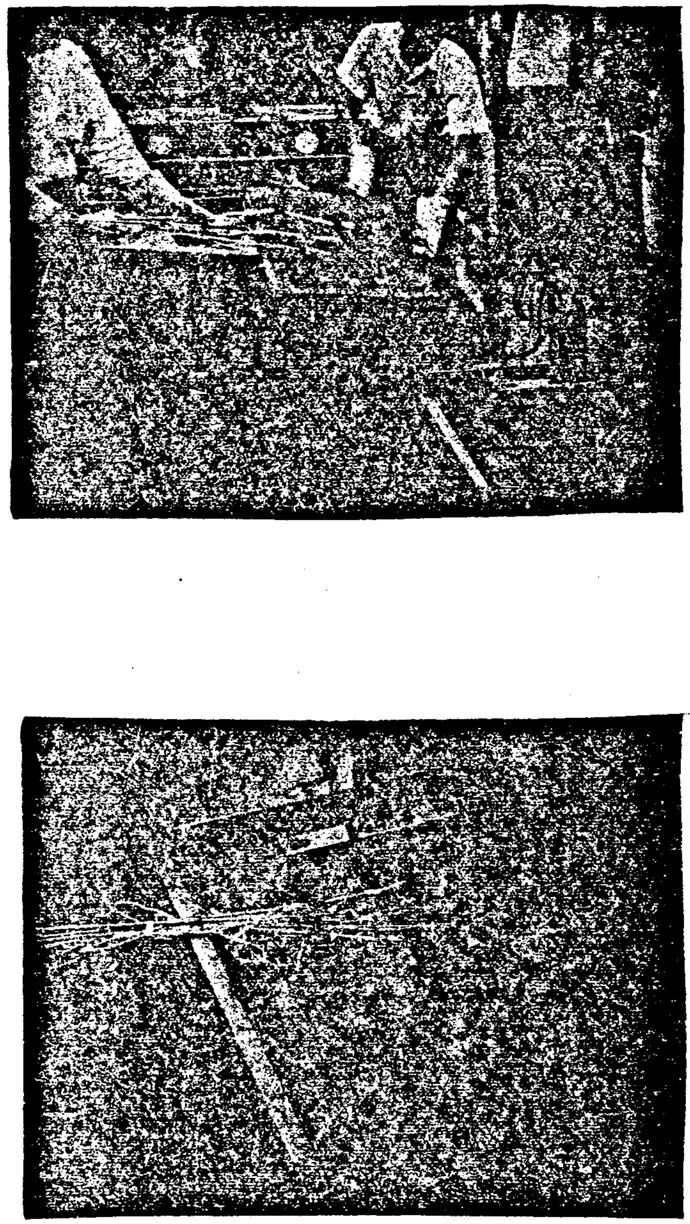


Figure 75 - Quenching Panel H into Liquid Nitrogen

The third panel, Panel J, was cooled to room temperature in place in the brazing die. After removing it from the retort, it was heated in air to 900°F for one-half hour, followed by quenching it into liquid nitrogen. There was no quenching distortion and the panel was flat; however, much of Panel J had crushed and/or dissolved core. Only a small portion of Panel J would be suitable for sandwich test specimens.

Photographs of the panels are shown in Figures 76 through 79. Photomicrographs are shown in Figures 80, 81 and 82.

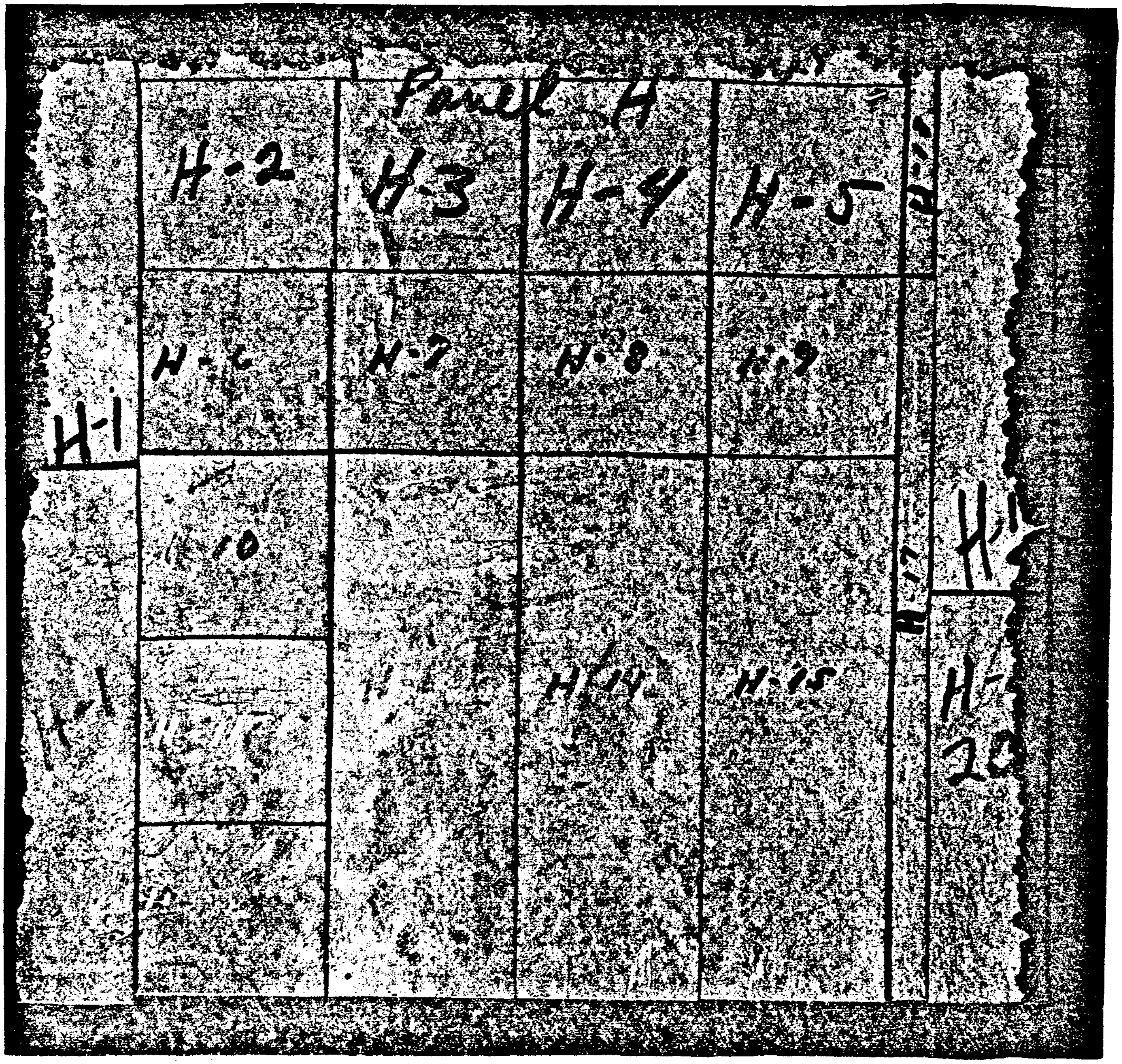


Figure 76 - Brazed Panel H Comprised of X7106 Faces, X7005 Honeycomb Core, and an Al-Ge-Si-Zn Brazing alloy

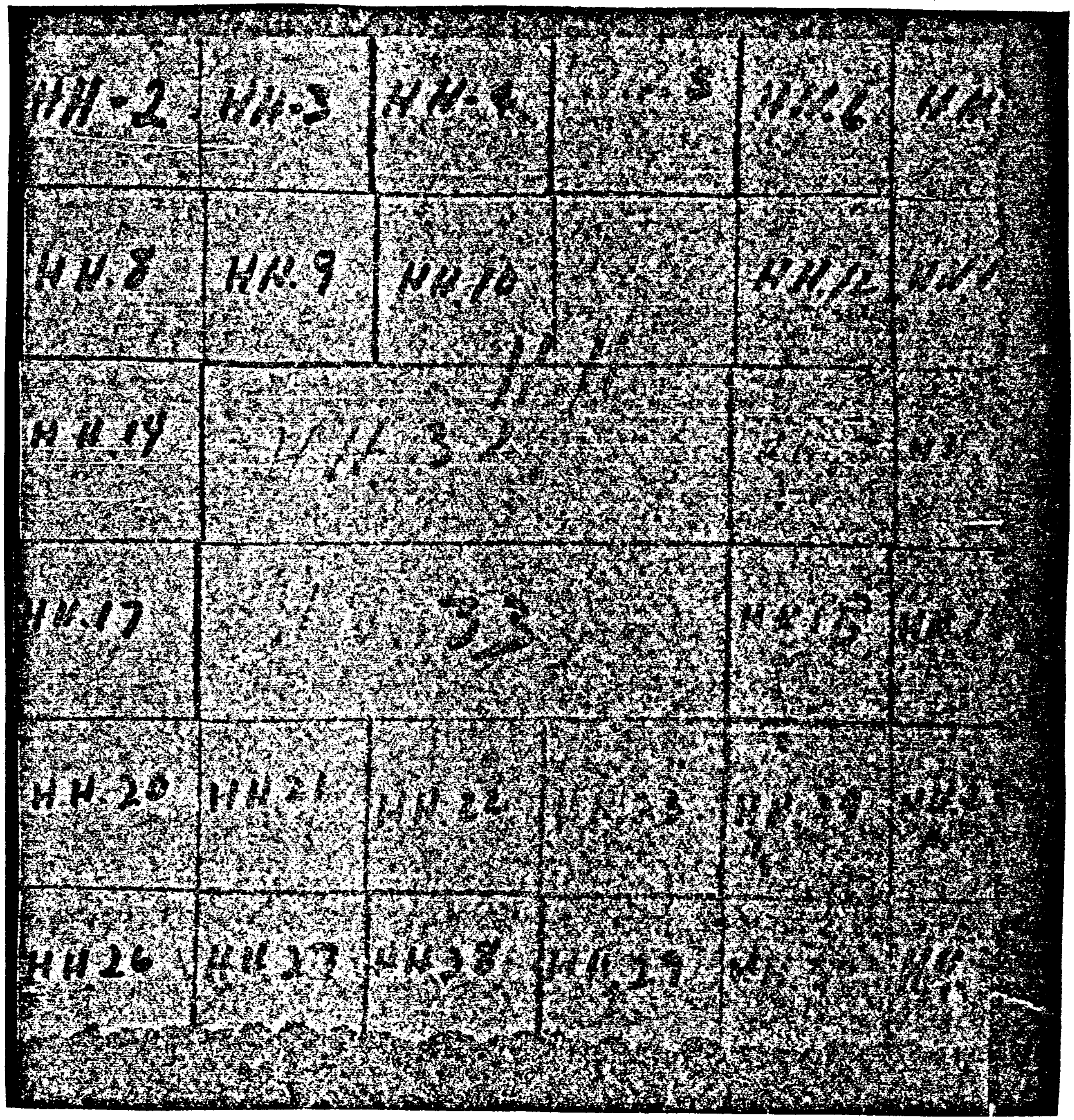


Figure 77 - Brazed Panel HH Comprised of X7106 Faces, X7005 Honeycomb Core, and an Al-Ge-Si-Zn Brazing Alloy

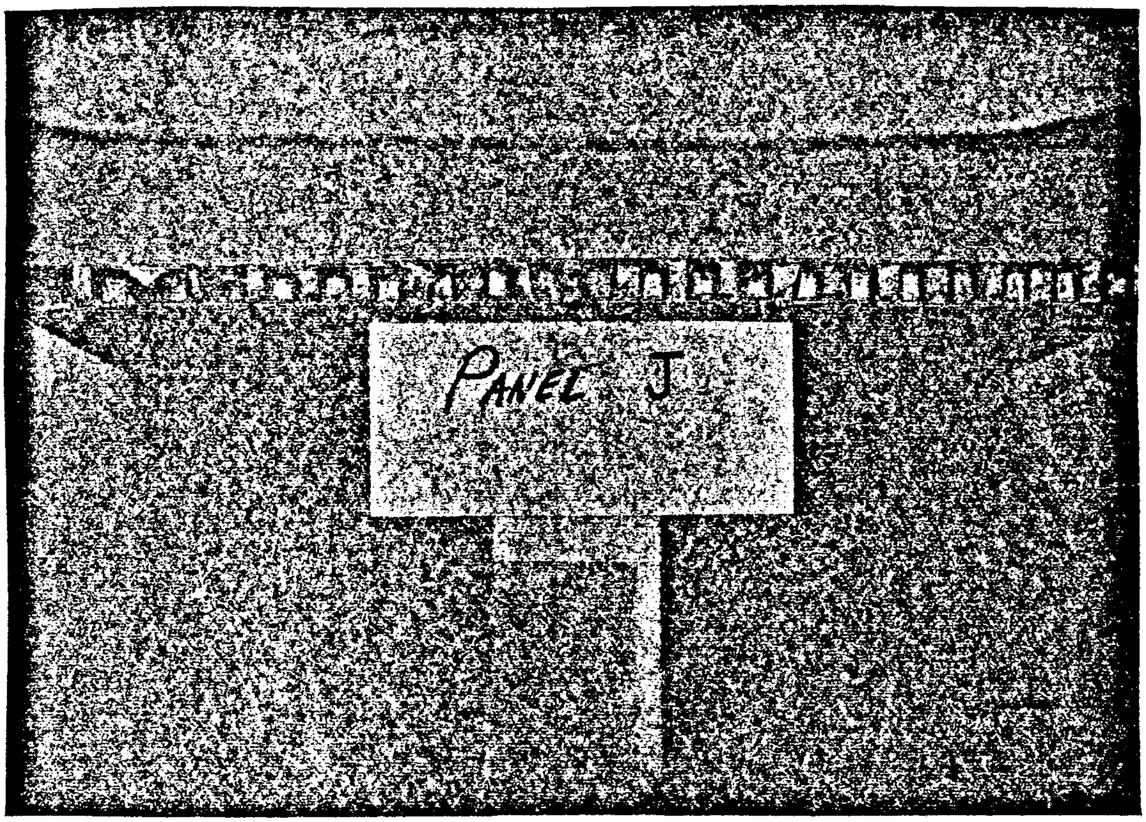
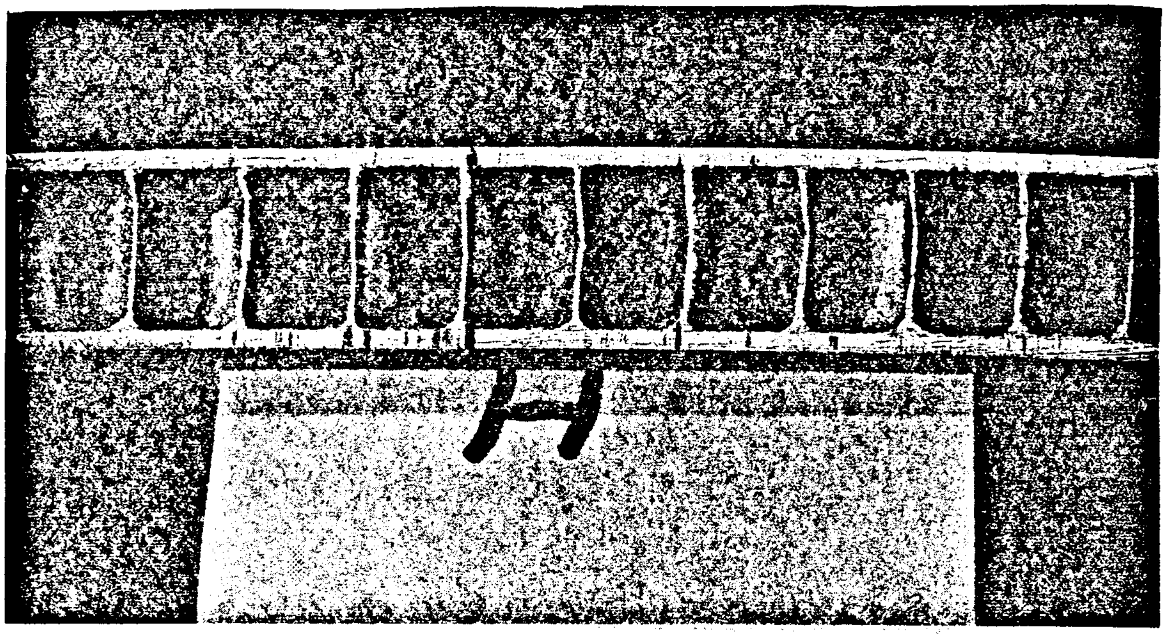


Figure 78 - Brazed Panel J Comprised of X7106 Faces, X7005 Honeycomb Core and an Al-Ge-Si-Ag Brazing Alloy



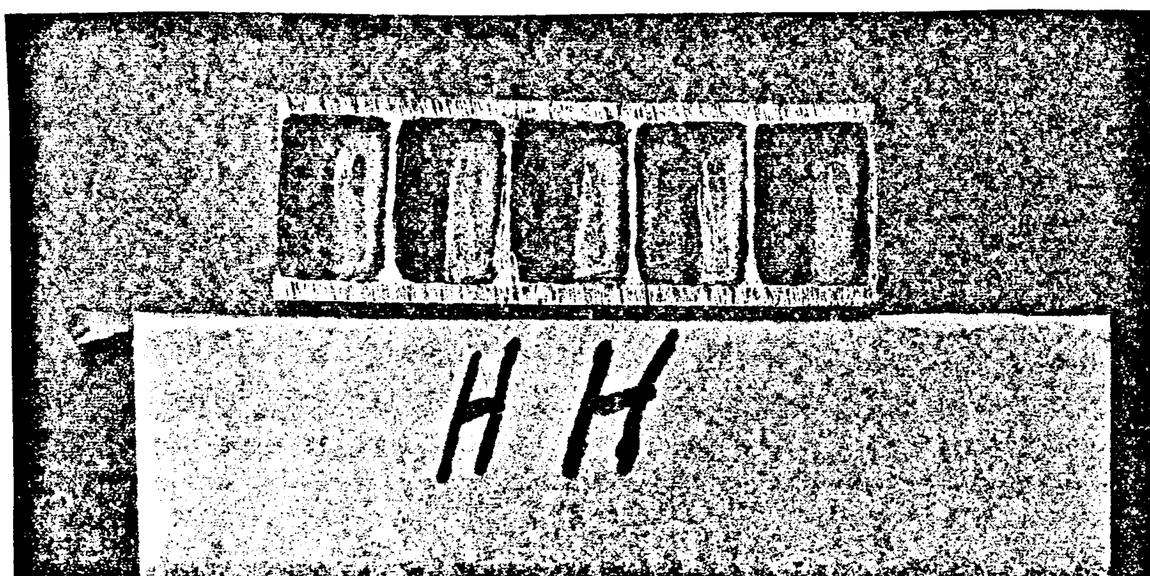


Figure 79 - Sections Cut from Brazed Panels H and HH Showing the Extent of Filleting and Core Node Flow

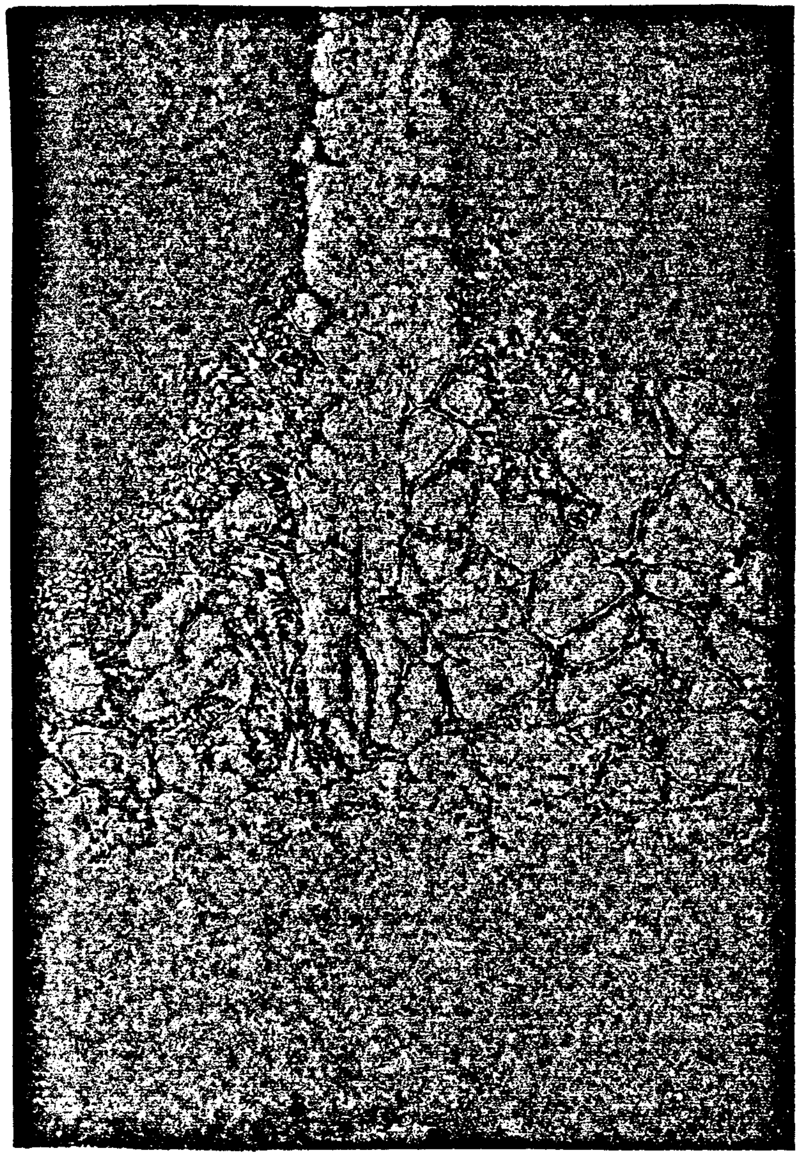


Figure 80 - Cross Section Photomicrograph of Core-to-Face Joint of Panel H

Mag.: 100X

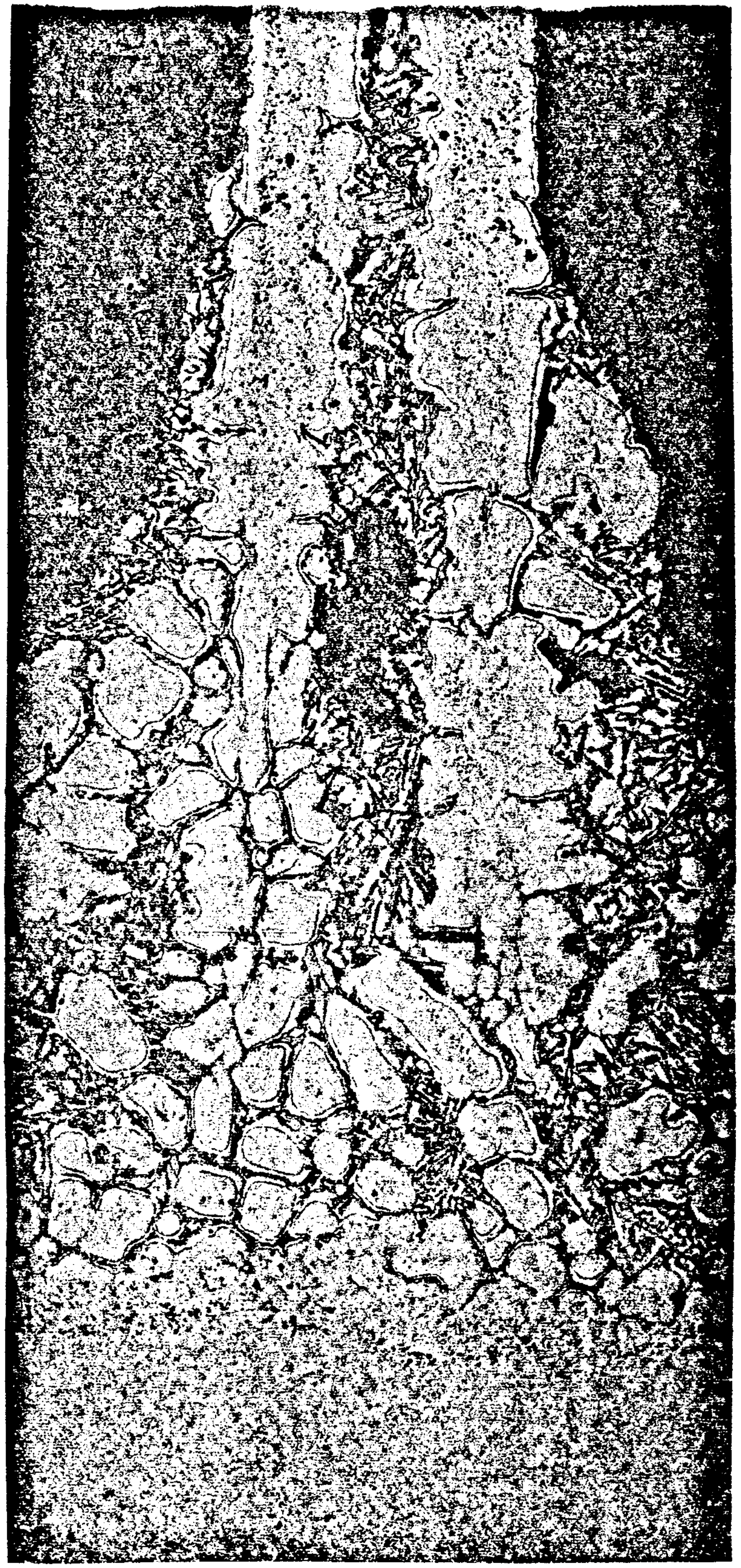


Figure 81 - Cross Section Photomicrograph of Core-to-Face Joint of Panel HH

Mag.: 100X

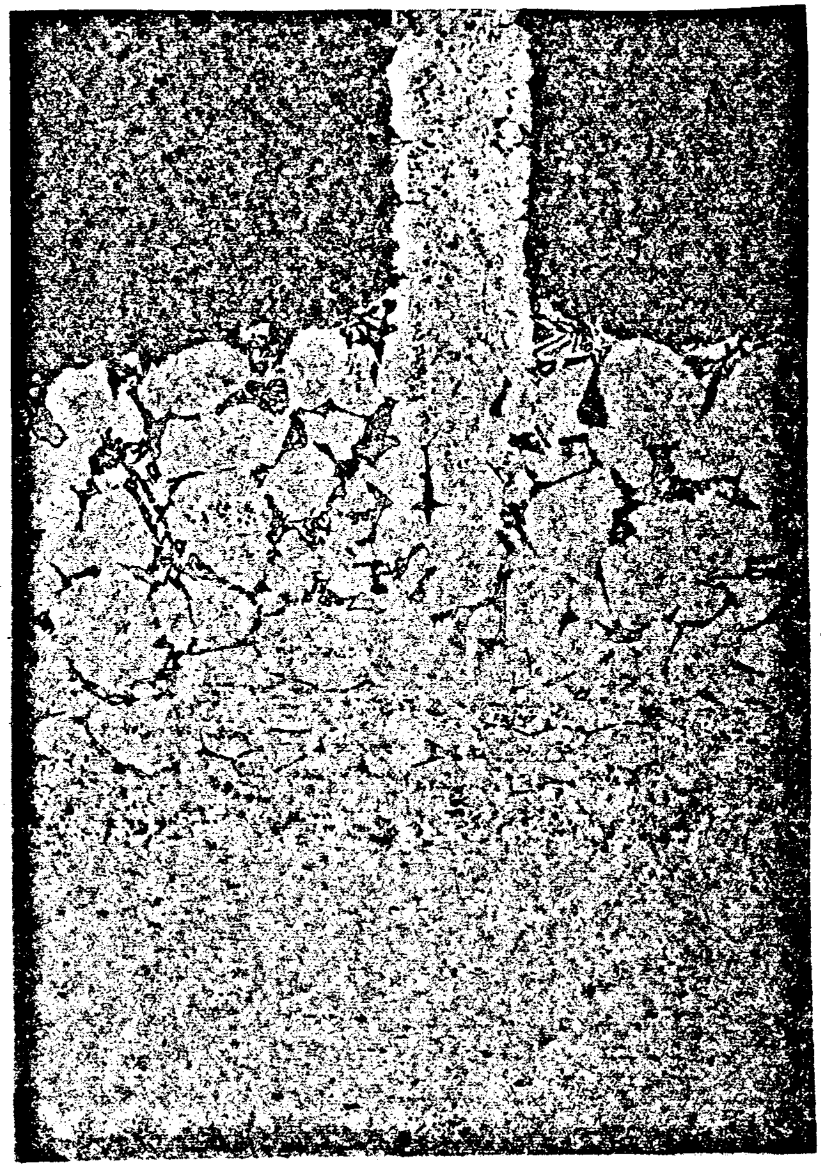


Figure 82 - Cross Section Photomicrograph of Core-to-Face Joint of Panel J

Mag.: 100X

Test Results

The mechanical properties of panels H, HH, and J are summarized in Figures 83 through 89, and the individual specimen test results are listed in Tables 45 through 48.

The data on tensile strength and tensile elongation indicate that the Al-Ge-Si-Zn brazing alloy did not adversely affect X7106 facing sheets as much as did the No. 719 brazing alloy. These data are substantiated by the photomicrographs, Figures 80 and 81, which show little or no diffusion of the brazing alloy into the sandwich facing sheets. The Al-Ge-Si-Ag brazing alloy was somewhat more aggressive; but, because the panel was over brazed, there is reasonable doubt concerning its ultimate characteristics.

Both of the experimental brazing alloys eroded the 0.005" thick X7005 honeycomb core more than did the No. 719 brazing alloy. Evidence of slight honeycomb core erosion is shown in the photomicrographs (Figures 80 through 82); but, the test results indicated a more pronounced effect. The flatwise tensile and compressive strengths, and the core shear strengths were substantially lower than for identical honeycomb core brazed with the No. 719 alloy. Contributory factors to lower core strengths resulting from the use of the two developmental brazing alloys, were the use of excessive amounts of the alloys and the probable excessively high brazing temperature.

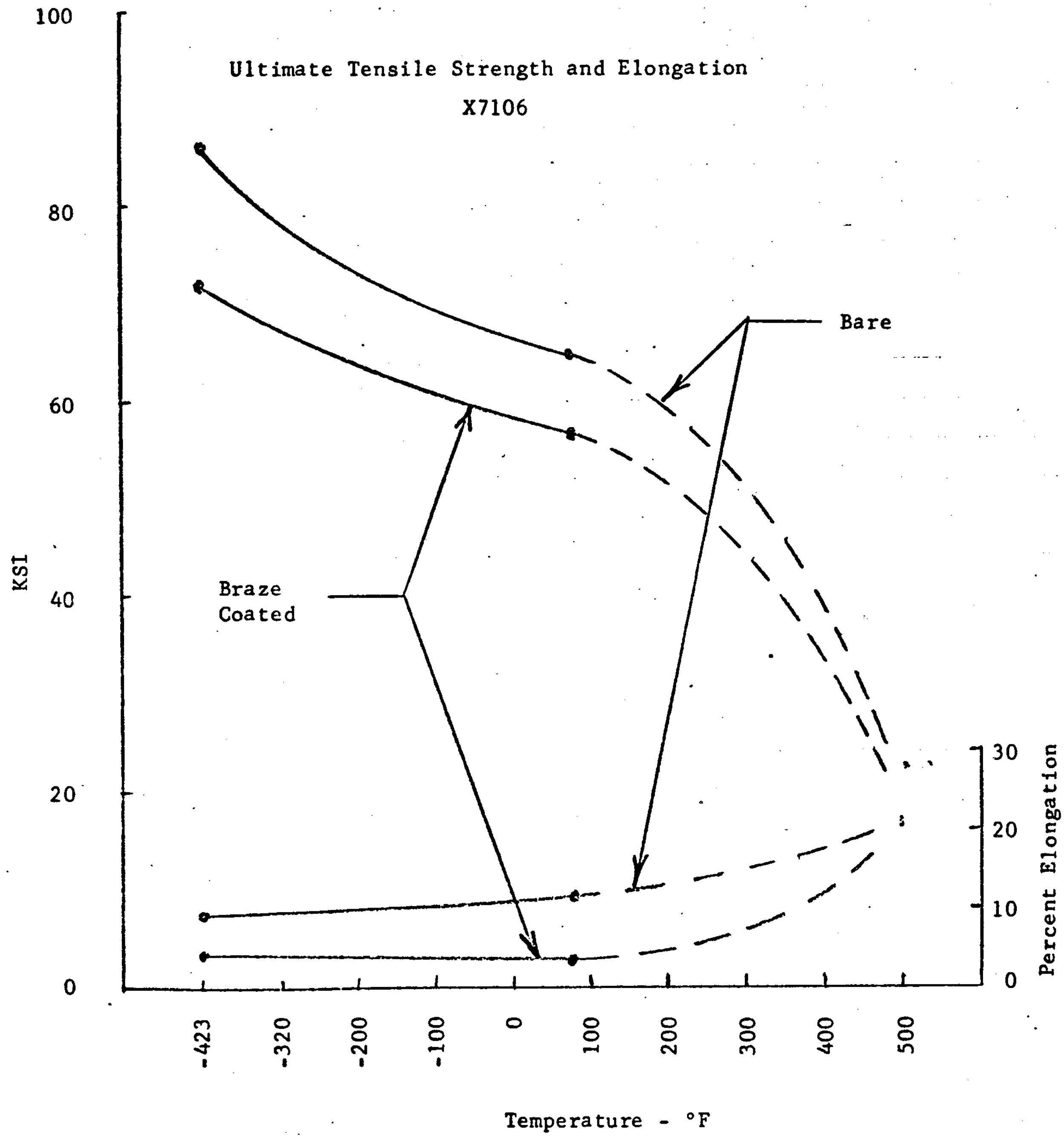


Figure 83 - Tensile properties of brazed sandwich facings and facing extensions (bare). The brazing alloy was 68Al-15Ge-7Si-10Ag.

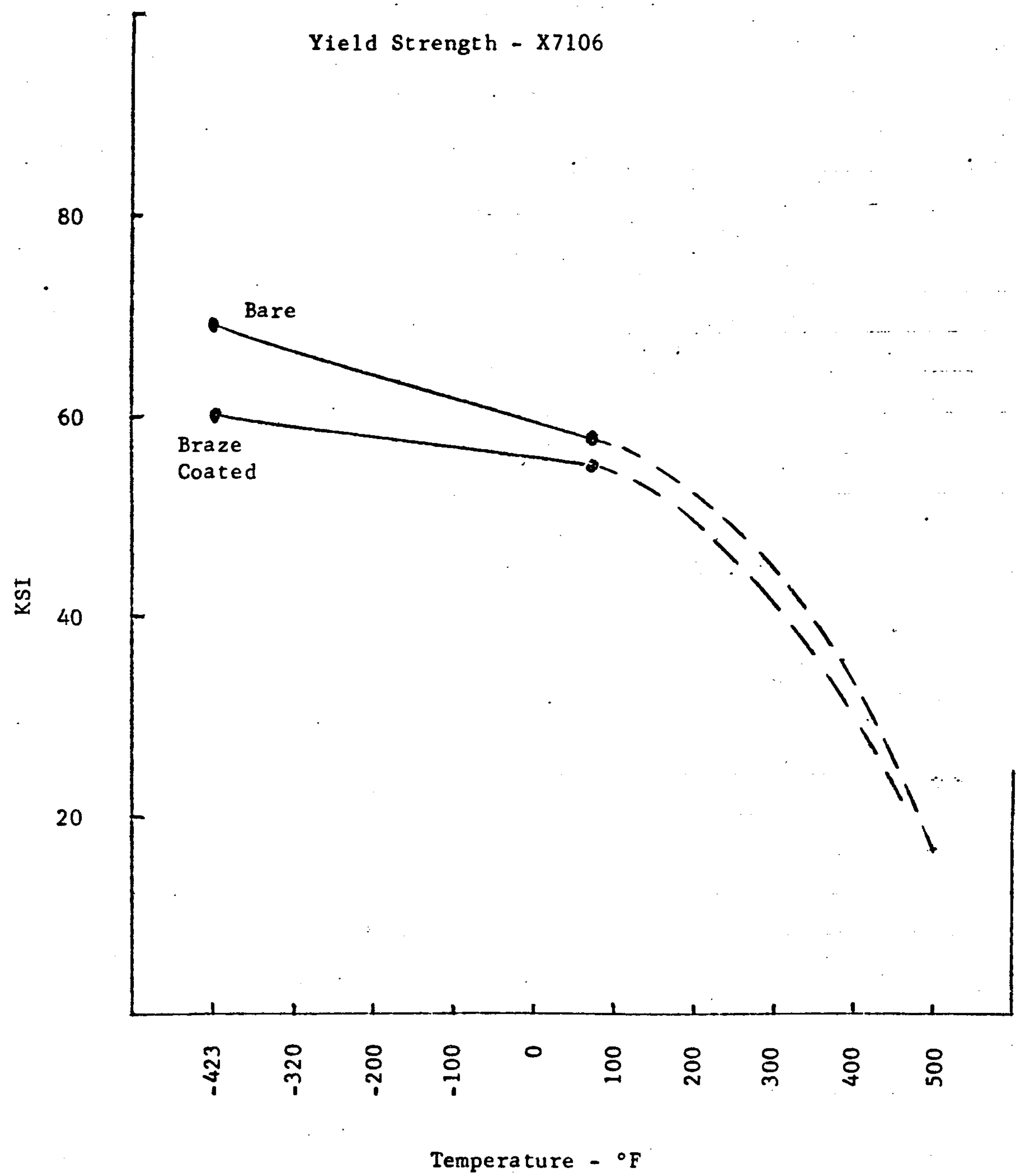


Figure 84 - Tensile properties of brazed sandwich facings and facing extensions (bare). The brazing alloy was 68Al-15Ge-7Si-10Ag.

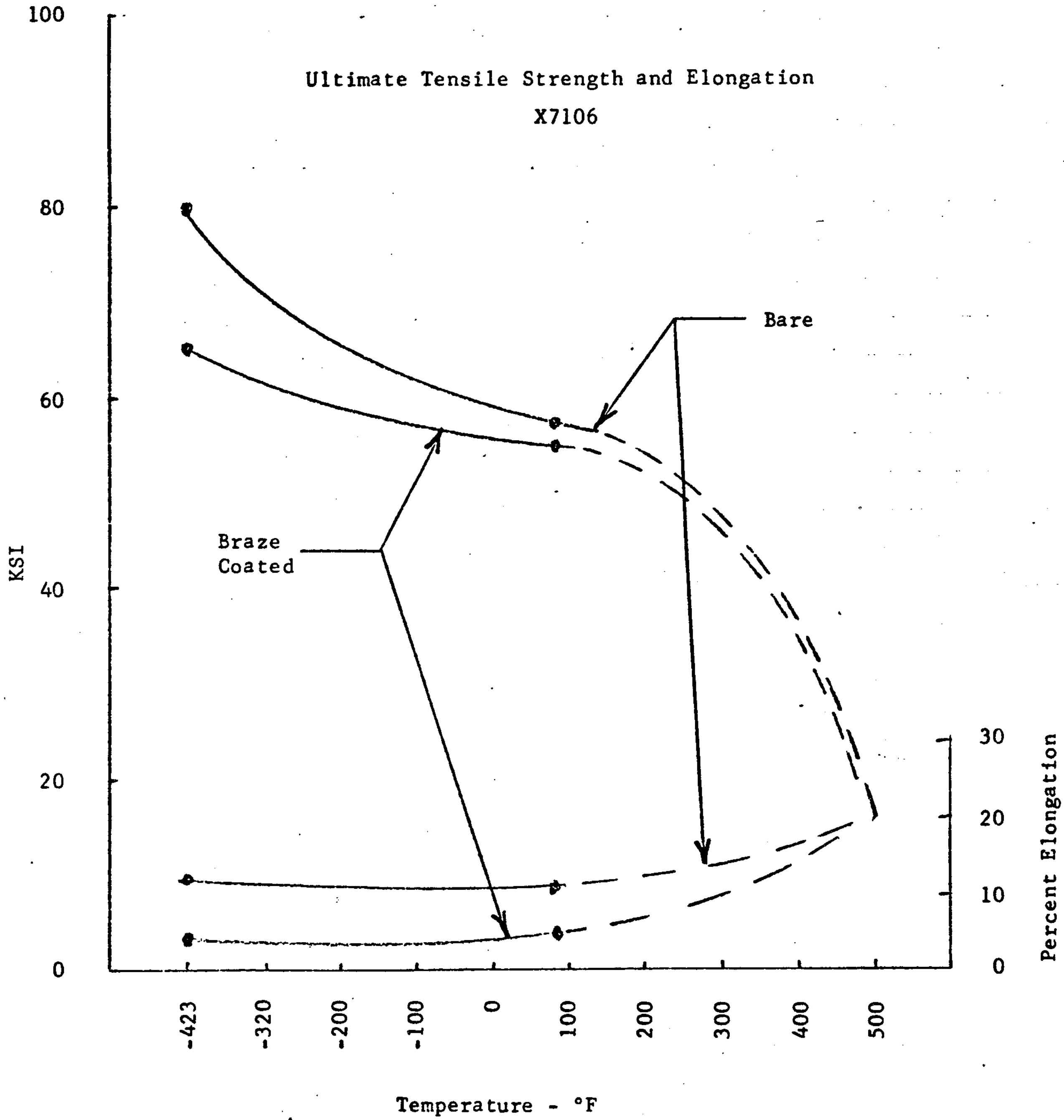


Figure 85 - Tensile properties of brazed sandwich facings and facing extensions (bare). The brazing alloy was 68Al-15Ge-7Si-10Zn.

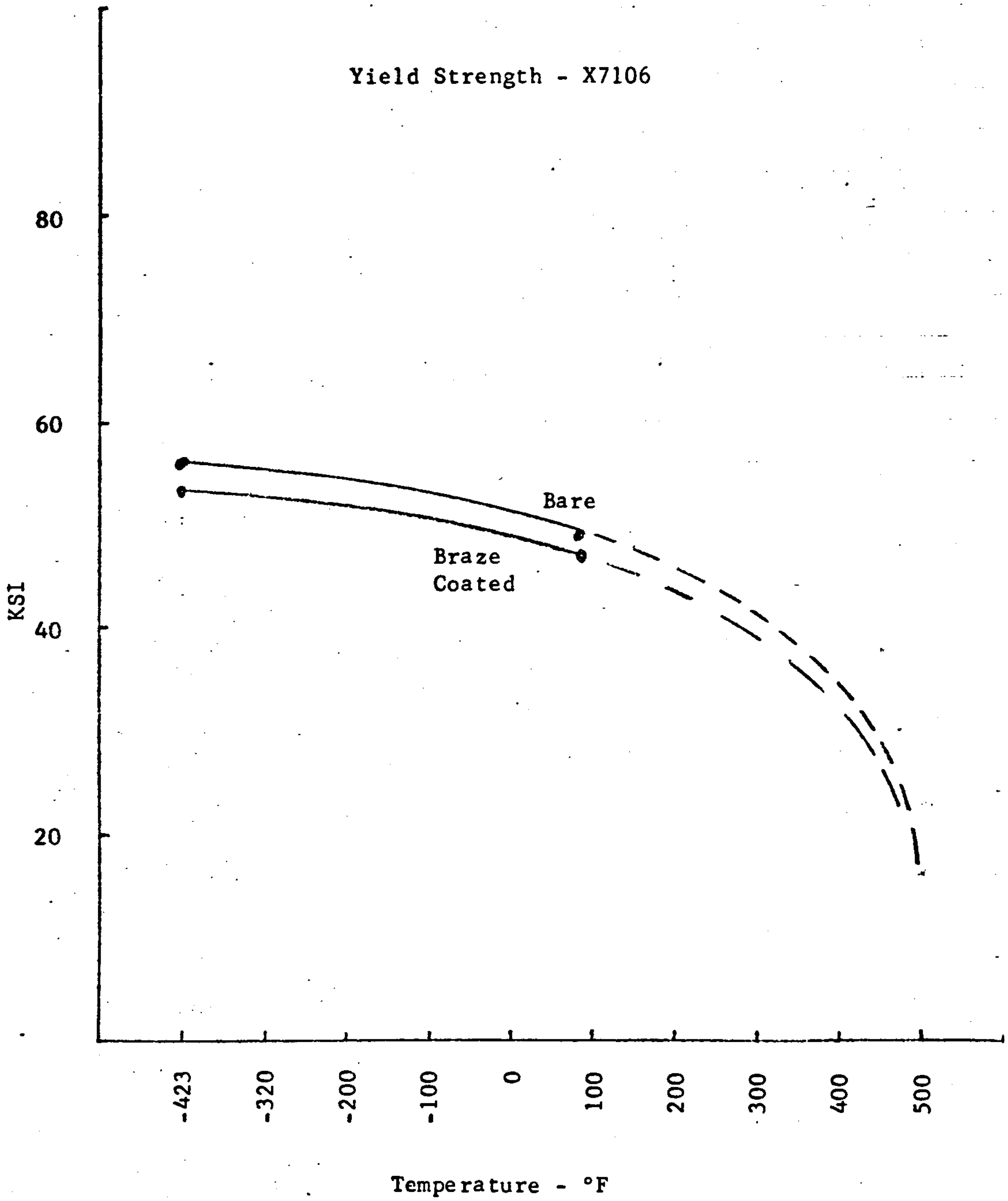


Figure 86 - Tensile properties of brazed sandwich facings and facing extensions (bare). The brazing alloy was 68Al-15Ge-7Si-10Zn.

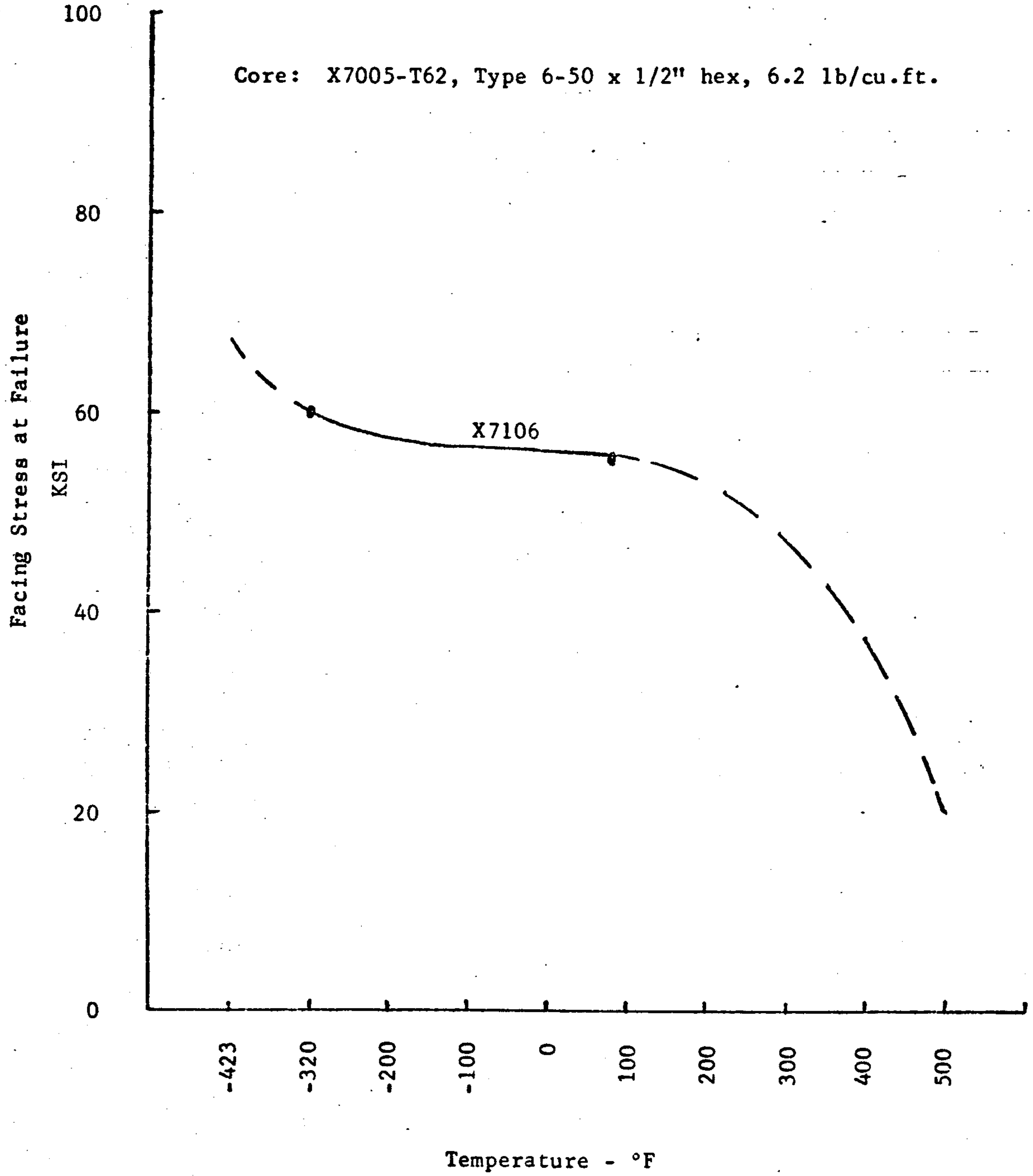


Figure 87 - Edgewise compressive strength of brazed aluminum honeycomb core sandwiches. The brazing alloy was 68Al-15Ge-7Si-10Zn.

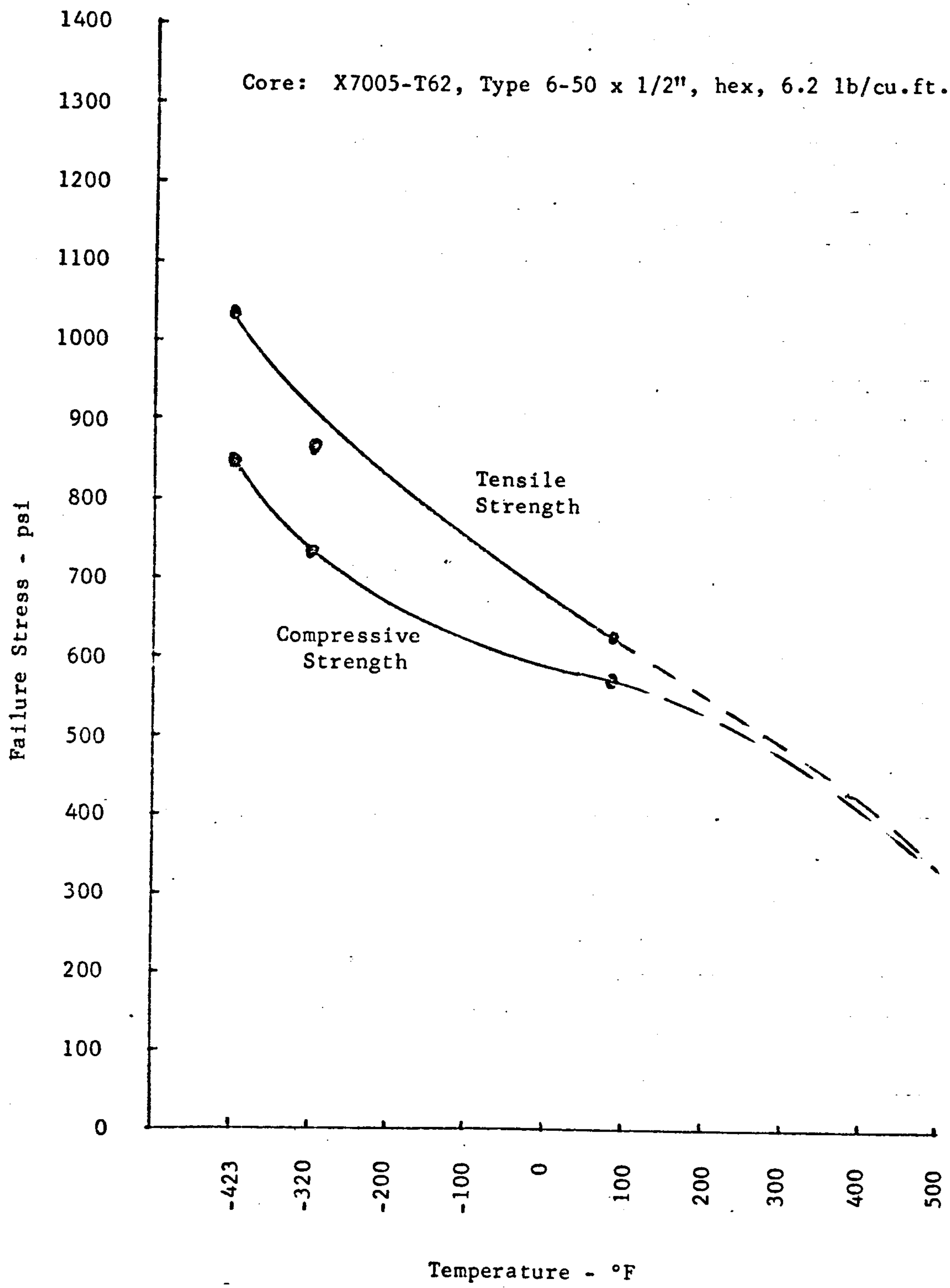


Figure 88 - Flatwise tensile and compressive strengths of brazed aluminum honeycomb core sandwiches. The brazing alloy was 68Al-15Ge-7Si-10Zn.

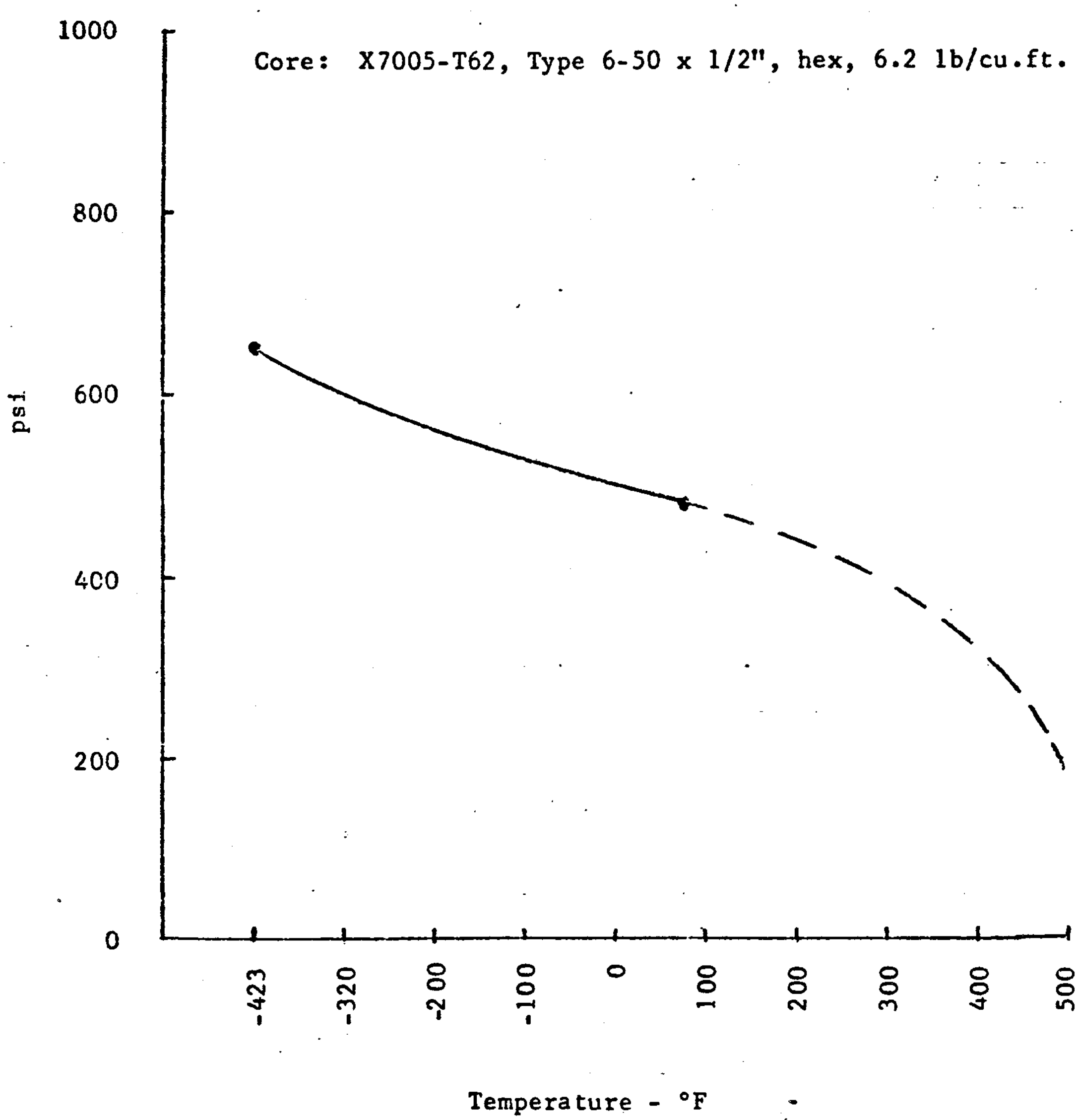


Figure 89 - Plate core shear strength of brazed aluminum honeycomb core sandwiches. The brazing alloy was 68Al-15Ge-7Si-10Zn.

TABLE 45

FACING TENSILE DATA - BRAZED PANEL J

X7106, 0.062" thick, coated with brazing alloy 68Al-15Ge-7Si-10Ag. Quenched into liquid nitrogen, aged 1 day at room temperature and 96 hours at 250°F.

Specimen Number	Test Temp. °F	Ultimate Tensile Strength psi	Yield Strength 0.2% Offset psi	Elongation Percent
J-1	-423	71,700	61,300	3
J-2		74,800	60,300	5
J-3		69,100	59,200	5
J-1	R.T.	58,700	56,000	2
J-2		55,200	53,700	3
Panel Extension - Not Braze Coated				
J-1	-423	85,500	68,400	7
J-2		87,200	68,500	9
J-3		88,400	69,500	9
J-1	R.T.	64,900	58,100	12
J-2		64,800	58,000	13

TABLE 46

TENSILE DATA - BRAZED PANELS H & HH

X7106, 0.062" thick, coated with brazing alloy 68Al-15Ge-7Si-10Zn. Quenched into liquid nitrogen, aged 1 day at room temperature and 96 hrs. at 250°F.

Specimen Number	Test Temp. °F	Ultimate Tensile Strength psi	Yield Strength 0.2% Offset psi	Elongation Percent
H-1	-423	68,100	51,100	7
H-2		65,300	51,100	4.5
HH-1		63,000	Not determined	3.5
HH-2		62,600	53,600	2.5
HH-1	R.T.	54,300	47,100	5
HH-2		54,600	47,000	5
		Panel Extension - Not Braze Coated		
H-1	-423	80,800	56,800	12
H-2		79,900	56,300	11
H-3		82,600	57,600	13
H-4		78,900	54,700	11
H-1	R.T.	56,900	49,000	10
H-2		56,900	49,100	12

TABLE 47

EDGEWISE COMPRESSION TESTS
BRAZED SANDWICH SPECIMENS H & HH

Faces:	X7106
Core:	X7005, Type 6-50 x 1/2", Hexagonal Cell
Brazing Alloy:	68Al-15Ge-7Si-10Zn
Nominal Specimen Size:	0.6" x 2" x 2"
Test Direction and Core Direction were parallel	

Specimen Number	Test Temp. °F	Facing Stress at Failure - psi	Failure Mode
HH-26	-320	68,400	Shear Crimping
HH-4		61,400	Shear Crimping
H-2		42,900	Facing Separation
HH-27	R.T.	49,200	Shear Crimping
HH-15		61,800	Shear Crimping
H-5		57,500	Shear Crimping

TABLE 48

PLATE CORE SHEAR TESTS
BRAZED PANELS H & HH

Faces:	X7106
Core:	X7005, Type 6-50 x 1/2", Hexagonal Cell
Brazing Alloy:	68Al-15Ge-7Si-10Zn
Nominal Specimen Size:	0.6" x 2" x 6"

Specimen Number	Test Temp. °F	Core Shear Stress psi	Core Shear Modulus psi
H-13	-423	660	Not Determined
HH		640	Not Determined
HH		610	Not Determined
H-1	R.T.	490	102,000
H-15		450	97,000
H-14		460	160,000

TABLE 49

FLATWISE TENSILE AND COMPRESSIVE TESTS
BRAZED SANDWICH SPECIMENS G & GG

Faces:	X7106
Core:	X7005, Type 6-50 x 1/2", Hexagonal Cell
Brazing Alloy:	68Al-15Ge-7Si-10Zn
Nominal Specimen Size:	0.6" x 2" x 2"

TENSILE TESTS

Specimen Number	Test Temp. °F	Failing Stress psi	Failure Mode
HH-8	-423	1250	Core Tear
HH-3		1025	Core Tear
H-6		810	Braze Line
HH-11	-320	>860	Tooling Adhesive
HH-24		>300	Tooling Adhesive
H-7	R.T.	280	Braze Line
HH-6		780	Core Tear
HH-28		550	Core Tear
HH-12		540	Core Tear

COMPRESSIVE TESTS

Specimen Number	Test Temp. °F	Failing Stress psi
H-8	-423	810
H-9		850
HH-10	-320	840
HH-16		680
HH-26		680
HH-21	R.T.	600
HH-18		590
HH-20		560
H-11		530

3. CONCLUSIONS AND RECOMMENDATIONS

3.1 Conclusions

The results obtained in this program have demonstrated the feasibility of inert atmosphere fluxless brazing of heat treatable aluminum honeycomb sandwich structures of X7005 alloy using No. 719 brazing alloy. Such honeycomb sandwich panels exhibited a high degree of retention of the base metal properties through the temperature range of -423°F-600°F. In particular, the flatwise tension and peel strengths were superior to adhesive bonded configurations.

It was concluded that optimum brazing alloy wetting and flow required the brazing alloy to be clad onto the substrate metal. The use of separately placed brazing alloy foil produced less than optimum results.

The experimental results from quenching and heat treating studies showed that aluminum honeycomb sandwich panels can be quenched into liquid nitrogen with minimum distortion. Consequently, high strength alloys with rapid quench rate requirements may be utilized for core and facing materials.

As in other reactive brazing systems, certain limits exist for the minimum material thickness that can be joined. For the materials evaluated and associated heating and cooling rates, the suggested minimum material gages are 4 mils for honeycomb core and 20 mils for facing material. The use of thicker gages would result in greater producibility.

Consequently, the best applications for brazed aluminum honeycomb sandwich would be for heavily loaded applications requiring thick facings with high core densities.

Brazing alloys of the systems Al-Ge-Si-Zn and Al-Ge-Si-Ag were developed that are promising for brazing X7106 at a temperature of approximately 1000°F. Preliminary results showed these brazing alloys to have less diffusion into X7106, with consequent higher retention of base metal properties, compared with the commercially available 716 or 719 brazing alloys.

3.2 Recommendations for Future Study

Several areas investigated during the program showed sufficient promise to warrant further extended study. These included the following:

1. Full Vacuum Brazing Techniques. In contrast to the inert atmosphere brazing system utilized on this program, full vacuum brazing applied to honeycomb sandwich panels offers certain positive advantages. Among these are the superior wetting and flow resulting from continuous deoxidation during brazing along with the use of minimal surface preparation requirements.
2. Brazing Alloys. Further refinement with minor composition variations and production in foil form for cladding onto the base metal is desirable. Both alloy systems Al-Ge-Si-Zn and Al-Ge-Si-Ag have shown promise and should be further modified to lower the melting point and determine the suitability for brazing 2219 aluminum alloy.
3. Braze Clad Alloys. The significant advantages of brazing alloys clad onto the base metal in terms of superior brazeability have been clearly demonstrated. The production development of a cladding system for the following combinations is recommended:

    Alloy 716 or 719 clad onto X7005 in foil gages for honeycomb core and sheet gages for facing material.

APPENDIX A - CALCULATIONS

Calculated Sandwich Properties for X7005 Alloy Honeycomb Core: (Ref. 1)

1. Core Density

$$\rho_c = \frac{2t_c}{S}\rho$$

$$\rho_c = \frac{2 \times .0054 \times 172.8}{.353}$$

$$\rho_c = 5.3 \text{ lbs/ft.}^3$$

t_c = foil thickness

ρ = material density

ρ_c = core density

S = cell size*

2. Core Shear Strength

$$F_s = .5\,\frac{\rho_c}{\rho}\,F_{su}$$

$$= \frac{.5 \times 6.2 \times 31,000}{172.8}$$

$$= 556.45 \text{ psi}$$

F_{su} = 31,000 psi

(Typical, Alcoa X7005 Green letter report)

ρ_c = 6.2 lbs/ft.^{3} actual

Assumes the core to have isotropic strength characteristics. The same additional comment noted in 3 applies.

3. Core Shear Modulus

$$G_c = 2.43\left(\frac{\rho_c}{\rho}\right)^{1.54} G$$

G = 3.9 x 10^6 psi (Alcoa X7005 Green Letter Report)

$$= 2.43\left(\frac{6.2}{172.8}\right)^{1.54} \times 3.9 \times 10^6$$

$$= 2.43\,(.0058) \times 3.9 \times 10^6$$

$$= 54,951 \text{ psi.}$$

Formula assumes the core to have isotropic strength characteristics. Honeycomb cores of this type exhibits directional shear and shear modulus characteristics when tested,depending on the ribbon direction, with transverse strength less than longitudinal.

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* Measured value which differs from the nominal 3/8".

Reference 1 - Formulas from NAA Honeycomb Sandwich Structures Manual.

4. Flatwise Compressive Strength

$$F'_c = 2.31\left(\frac{\rho_c}{\rho}\right)^{1.464} F_{cy}$$

$$= 2.31\left(\frac{6.2}{172.8}\right)^{1.464} \times 36,000$$

$$= 2.31 \times .0075 \times 36,000$$

$$= 623.7$$

F_{cy} = 36,000 psi (Alcoa X7005 Green Letter Report)

5. Flatwise Tensile Strength

$$F'_t = 1.578\left(\frac{\rho_c}{\rho}\right)^{1.247} \times F_{tu}$$

F_{tu} = 50,000 psi core material

$$= 1.578\left(\frac{6.2}{172.8}\right)^{1.247} \times 50,000$$

$$= 1270 \text{ psi}$$

SUMMARY

1. Core Density - 5.3 lbs/ft^3
2. Core Shear Strength - 556 psi
3. Core Shear Modulus - 54,950 psi
4. Flatwise Compressive Strength - 624 psi
5. Flatwise Tensile Strength - i270 psi

References: Formulas from NAA Honeycomb Sandwich Structures Manual

SYMBOLS

ρ	Material density
ρ_c	Honeycomb core density
t_c	Core foil thickness
S	Cell size
F_{su}	Material shear strength
G	Modulus of Rigidity
F_{cy}	Material compressive yield strength
F_{tu}	Material ultimate tensile strength

APPENDIX B

NOMINAL COMPOSITION AND MELTING RANGE OF BRAZING FILLER ALLOYS *

Alloy	AWS-ASTM Class	Silicon	Copper	Zinc	Approx. Melting Range--°F
4043 Wire	BAlSi-1	4.0-6.0	0.30	0.10	1070-1165
No. 713 Brazing Sheet	BAlSi-2	6.8-8.2	0.25	0.20	1070-1135
No. 714 Brazing Sheet	-------	10.0	----	----	1070-1100
No. 716 Brazing Wire and Flattened Wire	BAlSi-3	9.3-10.7	3.3-4.7	0.20	970-1085
No. 718 Brazing Wire and Sheet	BAlSi-4	11.0-13.0	0.30	0.20	1070-1080
No. 719 Brazing Wire	-------	9.5-10.5	3.5-4.5	9.5-10.5	960-1040
No. 805 Solder	-------	----	----	95	720
No. 806 Solder	-------	----	----	100	787

* Balance Aluminum